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# Magnetohydrodynamics (MHD) Engineering Test Facility (ETF) 200 MWe Power Plant

## Conceptual Design Engineering Report (CDER)

### Volume II — Engineering
### Volume III — Costs and Schedules
*(Included as Microfiche)*

Gilbert / Commonwealth
Engineers / Consultants

September 1981



Prepared for
National Aeronautics and Space Administration
Lewis Research Center
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for
**U.S. DEPARTMENT OF ENERGY**
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MHD-ETF
CONCEPTUAL DESIGN
ENGINEERING REPORT

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## 2.0 ENGINEERING SUMMARY

This section presents a summary of engineering design details for the principal systems, system operating modes, site facilities, and structures.

More detailed descriptions of the various systems, including facilities and functional requirements, may be found in the System Design Descriptions in Section 5.5.

The ETF resembles a coal-fired steam power plant in many ways. It is analogous to a conventional plant which has had the coal combustor replaced with the MHD power train. Most of the ETF components are conventional. They may, however, be sized or configured differently or perform additional functions from those in a conventional coal power plant. For example, the boiler not only generates steam, but also performs the functions of heating the MHD oxidant, recovering seed, and controlling emissions.

## 2.1 PLANT FACILITIES AND FUNCTIONAL DESCRIPTION

### 2.1.1 Major Structures and Site Facilities

#### 2.1.1.1 MHD Building

The MHD operating area contains the major MHD cycle components. Overall dimensions are 200 feet by 170 feet and the bay height is 100 feet. Special features include a combustor slag pit, a rail car and truck bay, a magnet area, consolidation equipment, and a 150 ton capacity crane.

#### 2.1.1.2 Turbine Generator Building

The turbine generator is located in a building with dimensions of 84 feet by 168 feet with four elevations to a height of 92 feet. Included in this structure are the control complex and the heater bay. Servicing this complex is a railroad access bay and a 100 ton capacity crane.

#### 2.1.1.3 Heat Recovery/Seed Recovery (HR/SR) Building

This building functions as an enclosure for the heat recovery equipment, namely, the radiant boiler, superheater, reheater, oxidant heater, and economizer. The HR/SR structure has eight elevations plus four intermediate platforms occupying an area of 112 feet by 140 feet to a height of 153 feet. A radiant boiler slag pit extends 11 feet below grade.

#### 2.1.1.4 Air and Oxidant Compressor Building

The ASU and Oxidant compressors are housed in a building to protect these high performance machines from the weather. This building has two elevations and is 84 feet by 140 feet and 86 feet high. The building is adjacent to the railroad bay. A 40 ton capacity crane on a 84 foot span services this area.

#### 2.1.1.5 Inverter Building

The inverter building, located adjacent to the MHD building, is 112 feet by 168 feet and 35 feet high. This building encloses the inversion equipment necessary for converting the MHD generated power from direct current (dc) to alternating current (ac). An additional 22 foot wide enclosed bay at the end of the inverter building houses the ac switchgear.

#### 2.1.1.6 Administration and Service Building

This building has two elevations and is 55 feet by 135 feet by 30 feet high. It contains the main machine shop, with a 20 ton capacity crane, and the auxiliary repair and maintenance bays.

#### 2.1.1.7 Yard Coal Handling

Included in coal handling facilities are:

1. Coal Pile Storage - Each compacted pile is 200 feet by 500 feet and 40 feet high. Each pile contains enough coal to operate at full load for 30 days.

2. Thawing sheds, dumper building, dumper pit and coal crusher house.

3. Coal feed building and coal system control building.

4. Coal pile runoff collection pond, 140 feet by 250 feet and a final collection pond, 240 feet by 440 feet.

2.1.1.8 Yard Seed Handling

The seed handling facilities comprise the following:

1. Seed unloading hopper shed and storage silos.

2. Seed feed building.

3. Spent seed silos.

2.1.1.9 Cooling Towers

The cooling tower complex contains eight mechanical draft units and, with the circulating water pumphouse, occupies an area of 140 feet by 145 feet.

2.1.1.10 Miscellaneous Buildings and Structures

Other significant plant features are:

1. Air Separation Unit Equipment Area (adjacent to compressor building)

2. Fuel Oil Tank, Dike and Pump House.

3. Main Guard House.

4. Substation.

2.1.2 <u>Power Subsystems and Their Functions</u>

2.1.2.1 Oxidant Supply

The Oxidant Supply System provides oxidant at the flow rate and pressure required for the operation of the MHD Power Train. An Intermediate Temperature Oxidant Heater (ITOH) of the HR/SR serves to preheat the oxidant to 1100°F prior to entering the MHD Power Train combustor.

A medium purity gaseous oxygen stream is produced in a cryogenic air separation unit (ASU). This stream is blended with atmospheric air in a mixing chamber to provide a stream with the required oxygen content. The oxidant stream is compressed by two parallel uncooled axial compressors driven by steam turbines.

The system provides liquid nitrogen (LIN) for cooling the superconducting magnet and gaseous nitrogen for auxiliary uses such as inert gas blanketing. Several features are incorporated in the design to facilitate plant startup. These include an electrically driven auxiliary oxidant compressor and storage of oxygen.

### 2.1.2.2 MHD Power Train

The MHD Power Train System generates alternating current (ac) electrical power from the combustion of coal using the Magnetohydrodynamic process and provides the thermal input for electrical power production in the steam bottoming cycle. It is the major portion of the ETF topping cycle and consists of the four subsystems:

1. The coal combustor, which produces the requisite high-velocity, high-temperature plasma.

2. The MHD generator which produces direct current (dc) electrical power. It consists of the MHD Channel, consolidation circuitry and a diffuser.

3. The inverter which converts the dc power to ac power compatible with the plant output requirements.

4. The MHD control subsystem which maintains required conditions in the MHD Power Train during operation.

Dc electrical power is generated in the MHD channel through the interaction of high velocity plasma with a magnetic field provided by a superconducting magnet which surrounds the channel. The electrical current is collected by finely segmented electrodes in the channel walls and combined into a few current sources by consolidation circuitry. The currents from these dc sources are then inverted to ac for transmission by the utility grid.

The plasma required for power production is produced by combusting pulverized coal with a pressurized oxidant and adding potassium seed to achieve adequate electrical conductivity. The high temperature needed to ionize the seed is obtained by enriching the combustion air with oxygen and preheating it to a temperature consistent with the state-of-the-art of metallic recuperators. Excess coal is used in the combustion process to limit the production of oxides of nitrogen ($NO_x$) caused by the high temperature, and to provide the necessary reducing condition in the HR/SR to limit the $NO_x$ in the exhaust gas.

Coal ash, released as a vapor in the combustion process, flows through the Power Train with the plasma. A portion of this ash condenses as slag on the containment walls where it protects them from erosion and insulates them from the high temperature plasma. However, the ash also tends to reduce the plasma conductivity and combines with the seed, resulting in some loss of seed. Therefore, the combustor is designed to reject a large fraction of the ash prior to the introduction of the seed.

The plasma enters the MHD channel from the combustor through a nozzle which *accelerates it to the high velocity needed for power production. Its*

pressure, temperature, and conductivity drop as it flows through the channel. The MHD energy conversion stops as the conductivity approaches zero, but the energy remaining in the gas is still satisfactory for powering the bottoming cycle. The gas is transferred for this purpose to the HR/SR System by the diffuser, which converts some of the kinetic energy of the gas into an increased static discharge pressure and meets inlet velocity requirements of the HR/SR.

The combustion gases lose large amounts of heat to the component pressure containment walls which must be recovered to improve plant performance. This is accomplished by cooling the components with boiler feedwater.

The design of the MHD Power Train is crucial to both the performance and cost of the entire ETF. The characteristics of the MHD Power Train largely determine the design parameters of the Oxidant Supply System, Magnet, HR/SR, and Steam Power Train. This is a result of the close integration of the topping and bottoming cycles. MHD Power Train design and operating parameters are established by maximizing the plant efficiency to minimize cost of compressor power, magnet length, and oxygen enrichment. Established design parameters include:

1. Channel length and lofting.

2. Peak magnetic field and profile.

3. Channel load factor profile.

Established operating factors include:

1. Oxygen enrichment factor

2. Combustor pressure

3. Channel Mach number

2.1.2.3 Magnet

The major functions of the superconducting magnet system are to:

1. Provide the high-intensity magnetic field in the large volume needed for MHD power generation, with minimum magnet system power consumption.

2. Operate as a self-contained system, maintaining the necessary cryogenic environment for its superconducting coils continuously without external support except for plant utilities (electric power, cooling water, etc.) and a supply of liquid nitrogen.

The minimum power consumption requirement is satisified by the use of superconducting (zero-resistive) windings in the magnet; viz: any other type of winding would involve power consumption so high as to outweigh the advantages of MHD power generation.

The superconducting magnet produces its high magnetic field within a cavity (warm bore) which extends through the middle of the magnet assembly and is open at both ends. It is necessary that the MHD channel be surrounded by a magnetic field. Therefore, the MHD channel is mounted in this cavity. The magnet warm bore must:

1. Provide the necessary internal volume for the MHD channel, associated structures piping and power leads, and provide access for connections.

2. Incorporate means to facilitate removal and replacement of the channel.

3. Incorporate means to protect the magnet against channel faults.

The warm bore of the ETF magnet is tapered, becoming larger toward the exit end, to accommodate the taper of the MHD channel. The ends of the warm bore are flared to maximize access.

To facilitate channel changeout, rollers and floor-mounted tracks are provided to permit rolling the magnet sideways. In addition, the magnet warm bore is equipped with internal tracks which support the channel and permit channel withdrawal in the downstream direction. Changeout is accomplished by unfastening flanges on removable sections near each end of the channel, rolling the magnet and channel aside to clear the diffuser, and then withdrawing the channel onto a special cart mating with the downstream end of the warm bore.

Protection for the magnet against channel faults is provided by an electrically insulating, water-cooled, warm-bore liner which is a part of the magnet assembly. Should a plasma leak occur in the channel wall, the insulation-coated inner surface of the liner serves as an ablative shield for a short period during which the MHD flow-train can be shut down. Should the plasma jet continue long enough to burn through the liner inner wall, a protective water deluge will ensue from the liner water passage.

It is also necessary that the magnet be protected against internal faults. Superconducting magnet windings are subject to an uncontrolled transition to the resistive state (a quench) under certain abnormal operating conditions such as loss of liquid helium coolant. Overheating and damage to windings can result. Protection against this contingency must be provided. The ETF magnet system incorporates quench detection circuitry which automatically triggers an emergency system to discharge the magnet before damaging the windings.

2.1.2.4 Heat Recovery/Seed Recovery System

Established design methods used in conventional fossil-fired steam plants are used wherever possible to meet the functional requirements of the Heat Recovery/Seed Recovery System.

The functional requirements are to:

1. Utilize the energy stored in the gases exhausting from the MHD power train.

2. Control the MHD power plant emissions.

3. Recover the seed.

The Heat Recovery/Seed Recovery System consists of a boiler and an electrostatic precipitator (ESP). The boiler utilizes the heat for:

1. Generating steam to power turbines to drive the electric-power generator and compressors.

2. Preheating the oxidant for the MHD Power Train.

3. Aiding in preheating the boiler feedwater.

The boiler resembles a conventional fossil-fired boiler which has had the burner replaced by the MHD power train. It generates steam in a balanced-draft, drum-type radiant boiler. Steam is also generated in the diffuser and transition section cooling jackets. The ETF boiler superheats and reheats steam and incorporates an economizer to heat the boiler feedwater. However, the ETF economizer recovers less heat than that of a conventional power plant, because cooling of the MHD combustor and channel provides most of the feedwater heating.

The boiler also contains the Intermediate Temperature Oxidant Heater (ITOH) which heats the 30 mol percent $O_2$ enriched oxidant, provided by the Oxidant Supply System, to 1,100°F before it is piped to the MHD combustor.

The boiler assists in controlling the plant emissions and recovering the seed. To do this, it must provide the proper conditions for the completion of various chemical reactions while the flue gases cool.

The flue gas entering the boiler contains a large amount of oxides of nitrogen ($NO_x$) as a result of the high temperature in the MHD combustor. The boiler reduces the $NO_x$ inventory by maintaining the flue gas in a reducing atmosphere at the proper temperature and stoichiometry for the time required to reduce $NO_x$ below the EPA's power plant effluent limits. This is performed in the entrance section of the radiant boiler known as the $NO_x$ Control Furnace.

The reducing atmosphere required for the $NO_x$ reduction process contains carbon monoxide and hydrocarbons which must be burned prior to release to the atmosphere. This is performed in a second radiant-boiler section known as the Afterburner. The combustion must be completed in a manner that not only minimizes the reformation of $NO_x$, but also maximizes the formation of $K_2SO_4$ rather than other sulfur compounds. The latter is required to meet the $SO_2$ emission standards and to recover the seed in a usable form.

A significant percentage of seed from the flue gas is recovered in the boiler. Both seed and slag condense on the heat transfer surfaces and are collected at the bottom of various chambers in the boiler. Because it is uneconomical to recover seed which has dissolved in slag, the boiler must be designed to physically separate the collection zones of the two substances. Although this is not entirely possible, the lower condensation temperature of the seed does

result in a preferential collection of the slag on the radiant boiler walls and of the seed on the convection heat transfer surfaces.

An electrostatic precipitator, which functions as a particulate control subsystem, completes the emissions control and seed recovery by capturing the condensed slag and seed particles entrained in the flue gases leaving the boiler.

2.1.2.5 Steam Power Systems

Exhaust gas from the MHD power train contains the energy which generates the steam in the HR/SR. This steam drives the conventional turbine generator and powers the auxiliary turbines. The high pressure turbine uses 1,071,000 lb/hr of steam at 1,815 psi and 1000°F and produces 45.7 MWe. Exhaust steam from the HP turbine is reheated to 1000°F and then split, with 679,000 lb/hr going to the intermediate pressure turbine (40.1 MWe) and, after extractions, 605,000 lb/hr going to the low pressure turbine (44.6 MWe). This steam exhausts to the main condenser at 2 in. Hg. After allowing for losses, a total of 128 MWe are generated by the turbine generator. The steam power cycle is shown schematically in Figure 2-1. Steam and water flow values may be found on the heat and mass balance diagram in Appendix 2A.

Hot reheat steam is delivered to the ASU compressor turbine for a power input of 12.3 MWe; to the two oxidant compressor turbines for an input of 23.4 MWe; and to the boiler feed pump turbines for an input of 2.6 MWe.

The steam side thermal efficiency is 39.7 percent.

2.1.2.6 Plant Auxiliary Systems

Two package boilers provide steam for plant heating and as needed for plant equipment such as the deaerators, demineralizers and flash tanks during startup and shutdown. Total steam output of the boilers is 200,000 lb/hr, but startup design requirements will ultimately determine final sizing.

The main function of the coal management facility is to transport pulverized coal from pressurized hoppers and inject it into the pressurized combustor. Coal handling facilities are capable of handling 2,000 tons per day with coal arriving in a unit train every five days.

The function of the Seed Management System is to receive and unload fresh seed at an average rate of 8,000 lb/hr, to recover and recycle spent seed at the rate of 16,800 lb/hr, and to mix and pulverize both seed streams for injection into the pressurized MHD combustor. The remaining spent seed (11,000 lb/hr) is trucked off-site for disposal or reprocessing.

Slag management consists of collecting, grinding, separating and transporting the condensed mineral fraction of the coal after combustion. The slag collected from the combustor and radiant boiler is ground and hydraulically removed to dewatering facilities. Dewatered slag is trucked off-site for disposal. The Slag Management System is designed to handle 10 tons per hour of combustor slag and 2-1/2 tons per hour of radiant boiler slag.

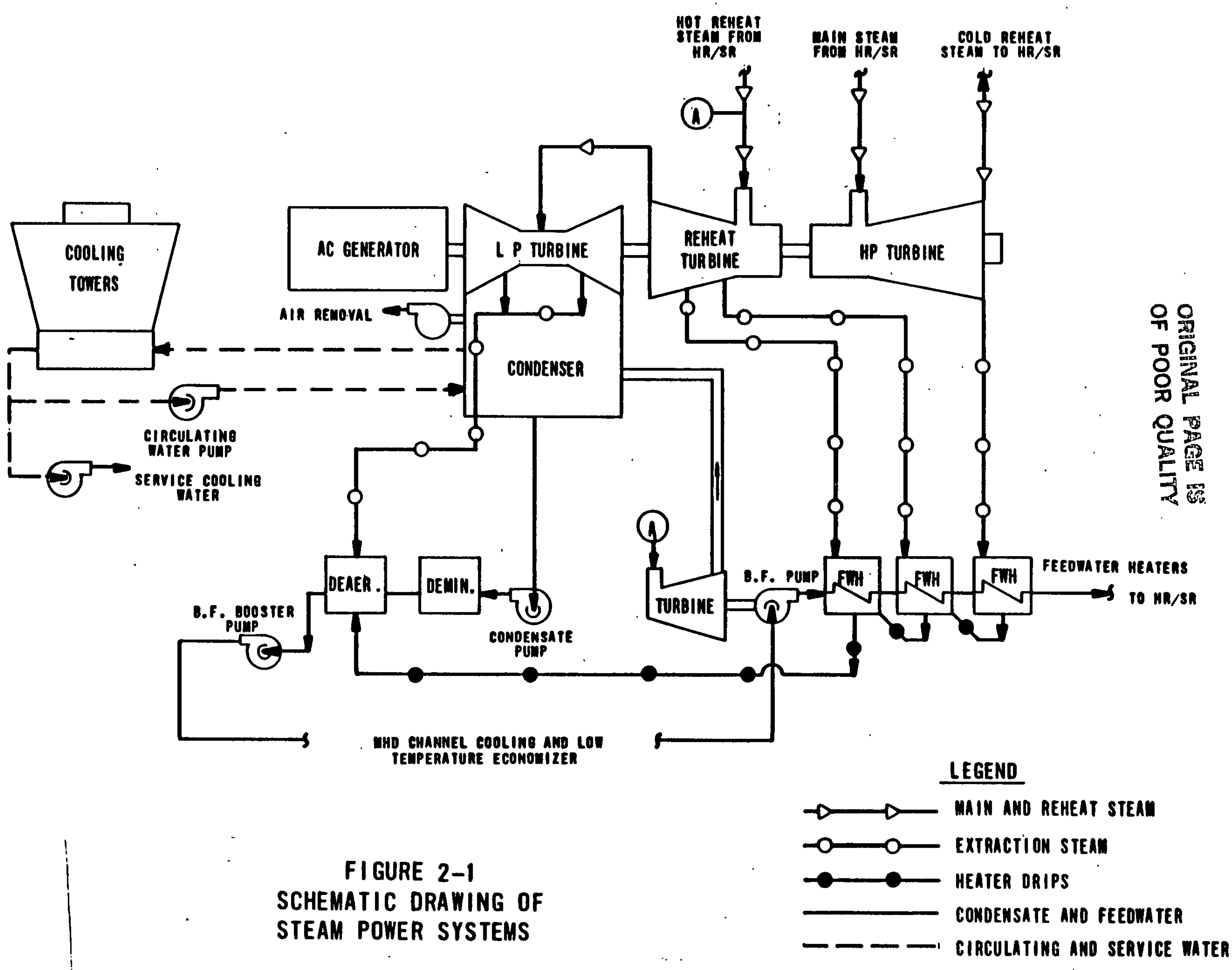


FIGURE 2-1
SCHEMATIC DRAWING OF
STEAM POWER SYSTEMS

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The electrical system delivers the electrical power generated by ETF to the utility grid; distributes power to the auxiliary systems for startup, shutdown, and normal operation; supplies emergency shutdown power when normal source is lost; and provides an uninterruptible power supply for essential plant equipment (such as computer, instrumentation, and controls (I&C)). A 138 kV substation ring bus is provided to act as an interface to connect the ETF topping cycle 34.5 kV inverter to the bottoming cycle 22 kV isolated phase bus through a unit connected step-up transformer. In addition, two station service step-down transformers provide 4.16 kV power to buses for in-plant power distribution.

2.1.2.7 Plant Services

Plant services include water management, heating, ventilating and air conditioning, cooling water, fuel oil, industrial and sanitary waste disposal, fire protection, and pneumatic systems. The design of these services follow conventional practice.

### 2.1.3 Plant Operating Characteristics

The ETF is designed as a baseload power plant. Major prime movers have electric motor drives so that startup power can be supplied from off site. Heating rates of equipment during startup from a cold start condition is controlled by the design of the bottoming plant equipment; e.g., the allowable heating rate of the steam generator is expected to be less than the cold wall MHD channel. This assumes, however, that magnet cooldown has been accomplished.

Present startup concepts include an oil-fired vitiation heater to provide initial power train heating and steam production. After gas temperatures between 1,800°F and 2,200°F are achieved, pulverized coal injection into the combustor can proceed.

The plant is designed for sustained operation down to 75 percent of rated load. Individual subsystems may have greater turn-down; i.e., the oxidant compressor (motor driven) is designed for controlled operation from zero to 50 percent of rated load.

At rated load, gross power* is 213.0 MWe. Auxiliary power, which is the electrical load to plant equipment to sustain plant operation, is 10.8 MWe. Net power to the plant busses for distribution is 202.2 MWe at a plant efficiency of 38 percent.

* Gross power, as used here, is the sum of the power produced in the MHD and steam turbine generators.

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## 2.2 DESIGN REQUIREMENTS AND CRITERIA

### 2.2.1 Operational Objectives

The system design and performance requirements for the ETF, as follows, were established by the Office of MHD, U.S. Department of Energy.

The ETF shall be a commercial prototype, with a fully integrated MHD topping/steam bottoming power plant, using coal and oxygen enriched air. The facility shall be a complete plant, rated at 200 MWe and capable of delivering electric power to a utility grid. The facility shall operate as a "baseload plant". The facility shall also accommodate a wide range load change, including load rejection and transients.

The ETF plant shall be capable of stable operation from 75 percent to 100 percent of the plant power rating, and shall be capable of reducing or increasing the power output within this range at rates of at least 3 MW per minute.

The ETF plant efficiency (net overall) shall be a minimum of 37 percent. The ETF shall be designed and constructed in accordance with utility practice for a thirty-year life.

The primary operational objective of the ETF plant is to demonstrate the commercial viability of power generation using an integrated MHD/steam combined cycle power plant. This plant will have a dual role to play, however, in that it will also be used to acquire experimental data on component performance under varying load conditions, interaction, and controllability of system components. This data can be acquired while the plant is producing power and supplying it to a utility grid.

The facility shall comply with applicable Federal, State, and local environmental regulations at all load levels.

### 2.2.2 Input Parameters

The ETF is designed to yield 200 MW net electrical power output while fired by a pulverized sub-bituminous coal from the Montana Rosebud seam. The as - received coal properties include:

| | |
|---|---|
| $H_2O$ | 27% maximum, by weight |
| Ash | 12% maximum, by weight |
| Sulfur | 1.1% maximum, by weight |
| HHV | 11,500 Btu/lb, typical dry |

The design average ambient site conditions for the ETF are:

| | |
|---|---|
| Dry bulb temperature | 42°F |
| Wet bulb temperature | 36°F |
| Ambient pressure | 13.0 psi |

These conditions are typical of those found in eastern Montana. The summer conditions for the cooling tower design are:

| | |
|---|---|
| Dry bulb temperature | 80°F |
| Wet bulb temperature | 59°F |

The summer wet bulb temperature will be exceeded less than 5 percent of the time for this area.

### 2.2.3 Design Requirements

The ETF Design Requirements Document (DRD) was the controlling document used in the preparation of a conceptual design. The DRD describes the purpose, general operating conditions, overall lay-out, and principal design characteristics of the ETF. It also defines basic plant requirements relating to performance, durability, reliability, availability, operating range, safety, and environmental effects. The DRD also presents design conditions of process flow streams for major system interface locations.

The configuration selected to achieve the operational objectives of the ETF conceptual design avoids new technology other than that essential to the operation of the MHD power train, magnet, and HR/SR systems. Values were established for a large number of interrelated design parameters and a number of system studies were undertaken to maximize performance while minimizing capital costs. Engineering judgement and/or theoretical analyses were used to establish selected parameters of the systems under development. These included combustor and channel heat losses, enthalpy extraction in the channel, maximum temperatures in the oxidant heater, etc. (See SDD-502, "MHD Power Train and SDD-504, "HR/SR System" for details.) The balance of the system design parameters were derived from the heat and mass balance described in Section 2.3.

## 2.3 SYSTEM HEAT AND MASS FLOW BALANCE

A system heat and mass balance diagram has been generated to provide a general thermodynamic description of the ETF and to illustrate the thermodynamic interaction of the major subsystems.

The following Table 2-1 is a summary of the power and efficiency for the current ETF design using 30 mol percent $O_2$ oxidant at 1100°F preheat:

TABLE 2-1
ETF OVERALL ENERGY BALANCE

| | | |
|---|---|---|
| FUEL INPUT | MHD POWER TRAIN COMBUSTION, MWt | 532 |
| GROSS POWER | | |
| | MHD POWER, MWe | 87.1 |
| | STEAM POWER, MW | |
| | Main turbogenerator | 130 |
| | Oxidant compressor | 23.4 |
| | ASU air compressor | 12.3 |
| | Boiler feed pumps | 2.6 |
| | TOTAL GROSS EQUIVALENT, MWe | 253.4 |
| AUXILIARY POWER | | |
| | OXIDANT COMPRESSOR, MW | 23.4 |
| | ASU AIR COMPRESSOR, MW | 12.3 |
| | BOILER FEED PUMPS, MW | 2.6 |
| | ELECTRICAL AUXILIARIES, MW | 10.8 |
| | INVERTER/TRANSFORMER LOSS, MW | 2.1 |
| NET OUTPUT | MWe | 202.2 |
| NET STATION EFFICIENCY, % | | 38.0 |

## 2.4 MHD PRINCIPLES AND TERMINOLOGY

### 2.4.1 MHD Principles

Magnetohydrodynamics (MHD) refers to the interaction of an electrically conducting fluid with a magnetic field, and to the use of that interaction to generate electricity. In an MHD generator, electrical energy is extracted directly from the kinetic and thermal energy of a fluid stream as it expands through a magnetic field. It is the electromagnetic analog of a turbine. The MHD topping cycle used in the ETF, which employs combustion gases in an open cycle, is thermodynamically equivalent to the Brayton cycle.

The principles of the MHD process are illustrated in Figure 2-2. Hot gas flows through the generator with velocity "U" at right angles to a strong magnetic field "B". The potassium seed, carried in the gas, is dissociated into electrons and positive ions forming a dilute plasma. The electrons and ions, as they move through the magnetic field, experience forces at right angles to both their direction of motion and the magnetic field direction. In accordance with the right-hand rule, the positively charged ions are forced toward the cathode electrodes while electrons (negative charge) are forced towards the anode electrodes. This gives rise to a net difference in electrical potential between the cathodes and anodes which is referred to as the Faraday voltage. Its gradient "$E_F$" is known as the Faraday field and the associated current is known as the Farraday current. The electrons, being much lighter than the positive ions, tend to move sideways more quickly, while the ions tend to travel downstream with the gas. This gives rise to a second potential difference, one between the inlet and exit ends of the generator, which is referred to as the Hall voltage. This gradient, "$E_H$", is directed upstream toward the generator inlet.

The existence of the Hall voltage requires the generator to be axially segmented into a large number of electrically isolated anode/cathode pairs. If the generator were built with a single pair of anodes and cathodes spanning the length of the generator, they would short-circuit this Hall voltage. A large Hall current would flow through the plasma from inlet to exit and return inside the electrodes, dissipating most of the electrical energy generated by the MHD process. The electrical power produced by the generator can be maximized by connecting each isolated anode/cathode segment pair to an individual load. Each anode/cathode pair becomes, in effect, an individual MHD generator, while the overall MHD generator is a composite of these individual units stacked end-to-end. This method of extraction, called Faraday loading, is theoretically simple but complex to build and operate. The net potential (voltage) within the generator, a sum of the Faraday and Hall voltages, generally increases both as the generator is traversed down its length and as the generator is traversed from one side to the other. Planes of constant potential thus intersect the walls of the generator diagonally, not at right angles. Because of this, an anode at one position in the generator will have the same potential as a cathode nearer to the generator inlet, and anodes and cathodes that are as the same voltage can be wired together. This is called diagonal connection. It simplifies the power extraction circuitry because the individual Faraday generators are essentially wired in series (like battery cells) into a single load circuit, greatly

# IDEAL FARADAY SEGMENTED MHD GENERATOR

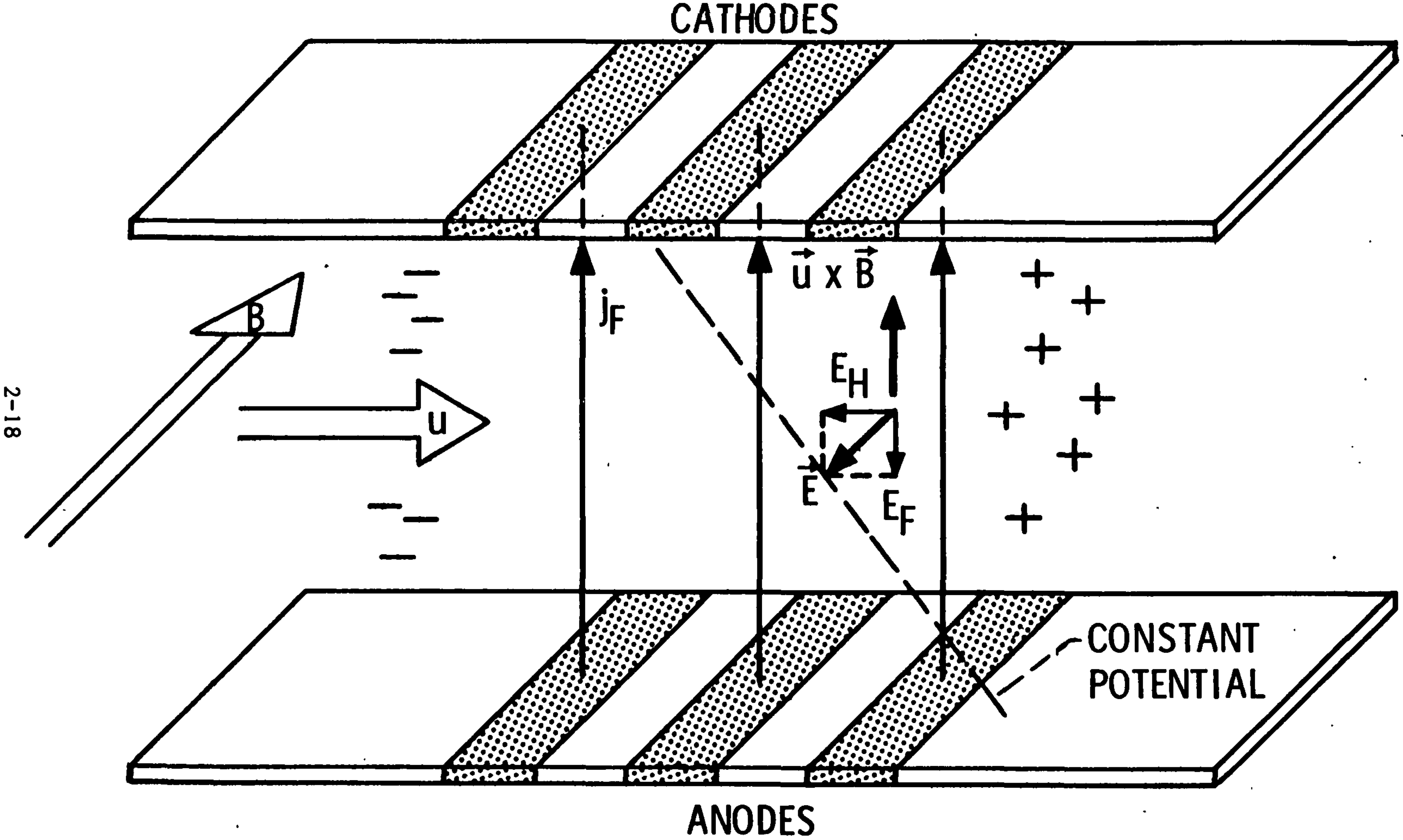


FIGURE 2-2

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reducing the number of electrical loads which the generator electrical system must handle.

The Hall voltage appears in the generator as a voltage difference between adjacent electrodes. Insulation is provided between electrodes to prevent this voltage differential from causing leakage currents across the insulator, arcing, or even destructive breakdown. To also help reduce these occurrences, the generator is designed so that the Hall voltage gradient is always less than 2,500 volts/meter and the voltage difference between electrodes (the product of the Hall field times individual electrode width) is less than 45 volts. Similar leakage problems are likely to occur on the insulating gas containment wall between the anodes and cathodes. Therefore, the generator is designed to keep the Farraday field less than 4,000 volts/meter. The current is kept below 10,000 amp/meter$^2$ to assure long electrode lifetime.

### 2.4.2 MHD System Terminology

The following sections provide definitions, terms and phrases which are used to discuss MHD generators. These definitions are specific to coal-fired, open-cycle MHD generators such as the ETF Power Train, and are not necessarily correct for other types of generators.

#### 2.4.2.1 MHD Generator

The MHD Generator converts energy from a hot plasma into electrical energy. The generator includes the MHD channel, the current consolidation circuitry, and the diffuser, but not the magnet. The magnet is considered a separate system. Because the generation of electricity occurs in the MHD channel, the term "generator" is frequently used synonymously with "channel".

#### 2.4.2.2 MHD Channel

The major component of the MHD generator is the channel. It is the duct through which the fast moving plasma stream is passed to yield part of its kinetic energy through the MHD process. The channel is located in a region of high magnetic field and provides controlled expansion of the gas stream against the retarding forces of friction and the MHD interaction with the magnet field. Electrodes line the channel walls at right angles to the field direction to collect the currents produced by these interactions.

#### 2.4.2.3 Plasma

Plasma is the fluid conductor used in a MHD generator and is a gaseous conductor of electricity. The plasma used in open cycle MHD is combustion gas that is highly ionized due to its temperatures and the addition of easily ionized materials (seed).

#### 2.4.2.4 Pressure Ratio

Pressure ratio is the ratio of inlet pressure to exit pressure of the gas stream flowing through the channel.

2.4.2.5 Enthalpy Extraction

The fraction of enthalpy extracted, usually expressed in percent, of the electric power produced by a MHD generator, vs. the thermal power flowing through it.

2.4.2.6 Channel Lofting

Channel lofting refers to the aerodynamic shape of the channel and ducts which expand and slow the gas stream. It is the variation of transverse dimensions of the duct with axial (i.e., the direction of flow) position.

2.4.2.7 Faraday Voltage

Faraday Voltage is the transverse voltage rise from a cathode to the opposing anode.

2.4.2.8 Hall Parameter

Hall parameter is a dimensionless number that relates axial current (along the direction of gas flow) to electric field strength in the channel.

2.4.2.9 Hall Voltage

Hall voltage is the axial voltage rise from the channel inlet to exit. Its overall magnitude can be much greater than the highest Faraday voltage.

2.4.2.10 Active Length

The distance from the beginning to the end of the MHD channel's active region (where significant power generation occurs) within the magnet field, is known as its active length. In the ETF, the active region begins at the inlet where the magnet field strength exceeds 4.0 teslas, and ends where it drops below 3.5 teslas at the exit.

2.4.2.11 Diagonal Connection

Diagonal connection is a method of externally loading a Faraday generator where individual cathodes are connected to individual anodes downstream which have the same voltage (due to the Hall voltage). The current zigzags several times through the length of the generator before being drawn off. It is equivalent to a series connection of Faraday electrode pairs.

2.4.2.12 Diagonal MHD Generator

A diagonally connected generator is that in which the connections are made by the diagonal bars forming the side walls of the generator.

2.4.2.13 Consolidation

Consolidation is the means used to organize the electrical energy extracted from the channel. The basic output from the channel is many hundreds of separate sources with different voltages and currents. The consolidation means will combine all these sources into only a few large sources, so that conventional power conversion and transmission equipment may interface with it.

2.4.2.14 Core and Boundary Layer

Basically there are two regions of plasma flow in the channel. The core is the region at the center of the flow (away from the channel walls), where the bulk of the MHD conversion process takes place. The flow is reasonably uniform and temperature and conductivity are high. The boundary layer is the region of the cold wall surface where the plasma properties are markedly different and result in thermal and electrical losses.

## 2.5 PLANT DETAILED DESCRIPTION

This Section provides a detailed description of the ETF, including the functional requirements, physical definition, and interface requirements for all major subsystems, facilities, and plant services.

In addition, separate sections address conventional hazardous wastes. Environmental considerations and intrusion are described in the appropriate technical subsystem description.

For more detailed system design information and the related drawings for each system, see the System Design Descriptions and related drawings in Section 5.5.

### 2.5.1 Oxidant Supply

The function of the Oxidant Supply System is to provide pressurized oxidant to the MHD Power Train at the pressure, temperature, and flow rate required for operation. The oxidant is prepared by blending ambient air with medium purity oxygen (70 percent oxygen by volume) produced by an air separation unit. The mixture is then compressed and passed to the HR/SR for heating to a higher temperature. The system is shown schematically on Figure 2-3. For detailed system design information and the related drawings for the system see SDD-501 in Section 5.5. Major elements of the Oxidant Supply System are:

Air Separation Unit (ASU),
ASU air compressors and auxiliaries,
Oxidant compressor, and auxiliaries.

System requirements include:

| Parameter | Remarks | |
|---|---|---|
| | 100% Rating | 75% Rating |
| Oxidant delivery oxygen content | 30% by volume | 30% by volume |
| Oxidant delivery pressure | 73 psia | 58 psia |
| Oxidant delivery flow rate | 867,852 lb/hr | 650,899 lb/hr |

Major interfaces are:

Steam power train,
Heat recovery/seed recovery system,
Circulating water system.

#### 2.5.1.1 Air Separation Unit (ASU)

The ASU produces a medium purity (70 volume percent) oxygen stream by separating air into its oxygen and nitrogen components in a cryogenic distillation column (column cold box). The ASU product is delivered as a gas at near ambient conditions. Some liquid oxygen and liquid nitrogen are withdrawn for storage for plant startup and magnet cool down.

Major elements of the ASU include:

Reversing heat exchanger (revex cold box) and reversing valves (valve cold box)
Lower and upper distillation columns (column cold box)
Expansion turbines and valves (expander cold box)
Impurity adsorbers (adsorber/exchanger cold box)

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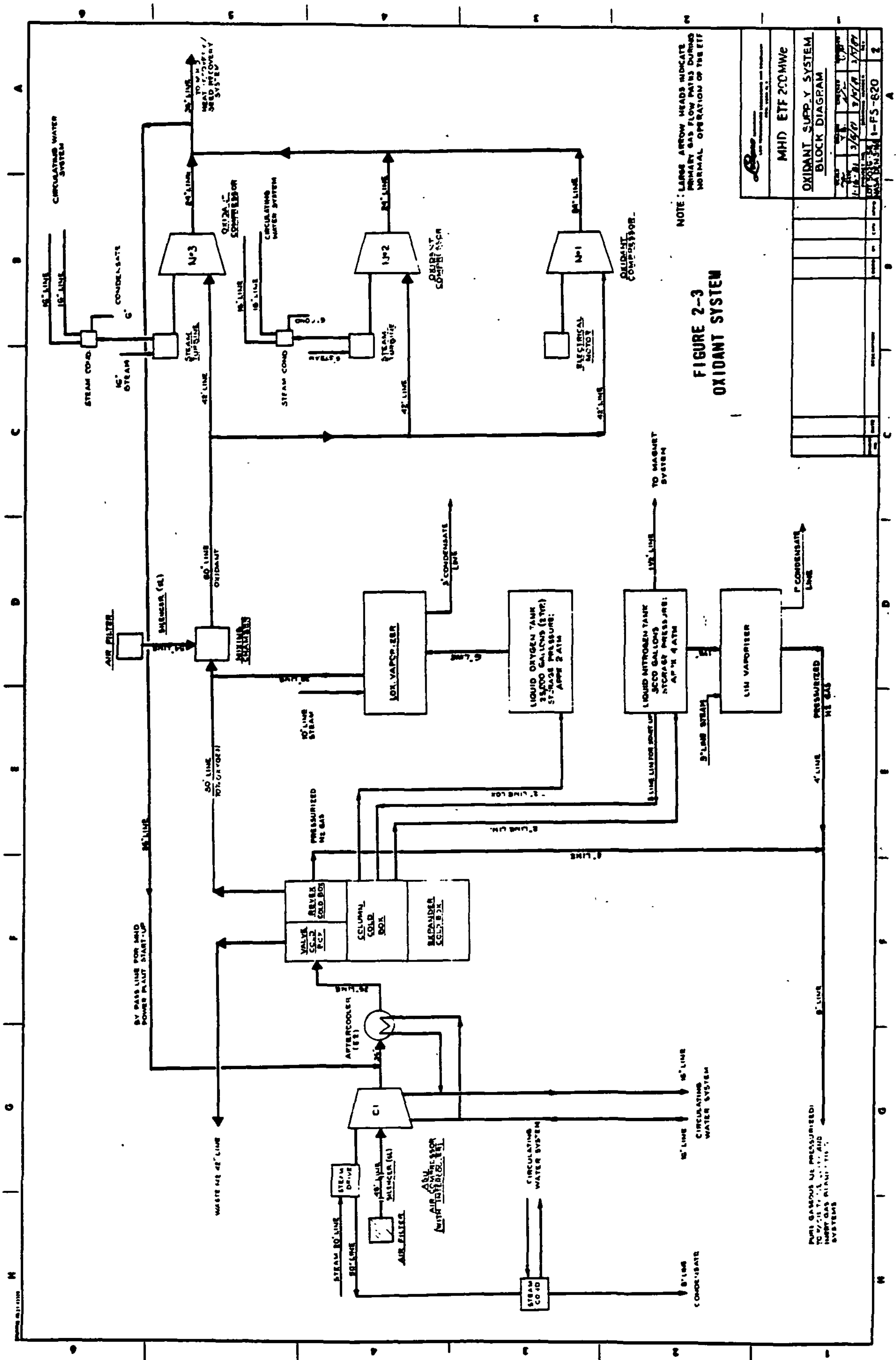


FIGURE 2-3
OXIDANT SYSTEM

TABLE 2-2
ASU SYSTEM REQUIREMENT

| Parameter | 100% Rating (nominal) | 75% Rating |
|---|---|---|
| Product oxygen pressure, psia | 13.5 | 13.5 |
| Product oxygen temperature, $^{o}F$ | 74 | 74 |
| Product purity, % $O_2$ by volume | 70 | 70 |
| Product flow rate, lb/hr | 172,101 | 129,415 |
| Capacity, tons per day of contained oxygen | 1,550 | - |

Table 2-4 shows air and oxidant compositions used in the ETF design.

2.5.1.2 ASU Compressor and Auxiliaries

The ASU air compressor supplies compressed, cooled air to the ASU. This compressor is a multi-stage, intercooled and aftercooled unit, consisting of two compression sections. The first section is an axial type compressor design, and the second section is a radial type compressor design. Circulating water from the cooling tower complex is used to intercool and aftercool the compressed air before delivery to the ASU. The ASU air compressor is sized for maximum efficiency at 100 percent rating. Power for the compressor is supplied by a steam turbine drive.

Major elements of the ASU air compressor (see Figure 2-3) include:

Filter and silencer
Compressor (C1) and steam turbine drive
Intercooler
Aftercooler (E2)

Tables 2-3, 2-4, and 2-5 show the design parameters for the ASU air compressor/steam-turbine drive system.

TABLE 2-3
ASU AIR COMPRESSOR REQUIREMENTS*

| Parameter | Remarks |
|---|---|
| Specific power consumption, kWh per ton of equivalent pure oxygen | 225 (maximum) |
| Delivery pressure, psia | 58.6 (at 100% rating) |
| Delivery pressure, psia | 55.6 (at 75% rating) |
| Capacity, lb/hr | 555,525 |
| Shaft power, kW | 12,275 (nominal) |

*At 13.0 psia input air

## TABLE 2-4

## AIR AND OXIDANT COMPOSITIONS

### Mol Percent

| | Dry Air | Ambient Air* | 70% $O_2$ ASU Product | 30% $O_2$ Oxidant |
|---|---|---|---|---|
| Nitrogen, $N_2$ | 78.084 | 77.626 | 26.879 | 68.160 |
| Oxygen, $O_2$ | 20.950 | 20.827 | 70.000 | 30.000 |
| Argon, Ar | 0.934 | 0.928 | 3.121 | 1.336 |
| Water Vapor, $H_2O$ | 0 | 0.587 | 0 | 0.478 |
| Carbon Dioxide, $CO_2$ | 0.032 | 0.032 | 0 | 0.026 |
| | 100.000 | 100.000 | 100.000 | 100.000 |

### Weight Percent

| | Dry Air | Ambient Air* | 70% $O_2$ ASU Product | 30% $O_2$ Oxidant |
|---|---|---|---|---|
| Nitrogen, $N_2$ | 75.519 | 75.238 | 24.152 | 65.111 |
| Oxygen, $O_2$ | 23.144 | 23.062 | 71.850 | 32.737 |
| Argon, Ar | 1.288 | 1.283 | 3.998 | 1.820 |
| Water Vapor, $H_2O$ | 0 | 0.368 | 0 | 0.293 |
| Carbon Dioxide, $CO_2$ | 0.049 | 0.049 | 0 | 0.039 |
| | 100.000 | 100.000 | 100.000 | 100.000 |

### Molecular Weight

| | | |
|---|---|---|
| Nitrogen, $N_2$ | -- | 28.013 |
| Oxygen, $O_2$ | -- | 31.999 |
| Argon, Ar | -- | 39.948 |
| Water Vapor, $H_2O$ | -- | 18.016 |
| Carbon Dioxide, $CO_2$ | -- | 44.0101 |

### Densities at 60°F and 14.7 psia (lbm/ft$^3$)

| | |
|---|---|
| Nitrogen, $N_2$ | 0.07378 |
| Oxygen, $O_2$ | 0.08428 |
| Air | 0.07630 |
| Oxidant (30 mol % $O_2$) | 0.07722 |

* Based on

$T_{dry\ bulb}$ = 42°F
$T_{wet\ bulb}$ = 36°F

## TABLE 2-5

### ASU AIR COMPRESSOR/STEAM TURBINE SYSTEM DESIGN PARAMETERS

| | 100% Rating | 75% Rating |
|---|---|---|
| **Filters and Silencers** | | |
| Pressure Drop, psi | 0.2 | 0.1 |
| **Gas Cooling** | | |
| Gas Pressure Drop, percent | 1.5 | 1.5 |
| Gas Discharge Temperature, °F | 84 | 80 |
| Cooling Water Temperature, °F | 74 | 74 |
| **ASU Air Compressor** | | |
| Section Polytropic Efficiency, percent | | |
| Section 1 (axial) | 87 | 86 |
| Section 2 (radial) | 80 | 79 |
| Discharge Pressure, psia | 56.6 | 53.7 |
| Flow Rate, lb/hr | 555,525 | 433,675 |
| **Steam Turbine Drive** | | |
| Efficiency, percent (overall) | 80 | 78 |
| Steam Inlet Temperature, °F | 1000 | TBD |
| Steam Inlet Pressure, psia | 395 | TBD |
| Steam Discharge Pressure, psia | 1.23 | TBD |

2.5.1.3 Oxidant Preparation

Oxidant preparation blends incoming atmospheric air with oxygen product from the ASU in a mixing chamber (see Figure 2-3) to provide an oxygen enriched stream suitable for operation of the MHD Power Train. The blended oxygen stream is compressed by uncooled axial type compressors (No. 2 and No. 3, Fig. 2-3) rated for 40 mole percent oxygen enriched air service. The oxidant compressors are sized for maximum efficiency at 100 percent rating. Power for these compressors is supplied by two steam turbine drives and one motor drive.

Three 50 percent compressors are used for redundancy. One compressor (No. 1, Fig. 2-3) is driven by an electric motor to facilitate startup and to act as a standby unit. Liquid oxygen storage is also provided for startup and to improve plant availability. Liquid nitrogen storage is provided for magnet cryogenic and plant auxiliary uses.

Major elements include:

- Filter and silencer
- Mixing chamber
- Oxidant compressor with electric motor drive
- Oxidant compressors with steam turbine drives (2)
- Liquid oxygen and liquid nitrogen storage tanks
- LOX and LIN vaporizers

Table 2-7 shows the design parameters for oxidant preparation. Based on these design parameters and the required oxidant flow, the oxidant preparation requirements are shown in Table 2-6:

TABLE 2-6
OXIDANT PREPARATION REQUIREMENTS

| Parameter | 100% Rating | 75% Rating |
|---|---|---|
| Oxidant delivery pressure, psia | 73.5 | 55.0 |
| Oxidant delivery flow rate, lb/hr | 867,852 | 650,899 |
| Oxidant delivery oxygen content, by volume | 30% | 30% |
| Oxidant compressor power, kW (nominal) | 23,448 | - |

TABLE 2-7

OXIDANT PREPARATION SYSTEM
DESIGN PARAMETERS

| | 100% Rating | 75% Rating |
|---|---|---|
| Filters and Silencers | | |
| Pressure Drop, psi | 0.2 | 0.1 |
| Mixing Chamber | | |
| Discharge Oxygen Content, percent by volume | 30 | 30 |
| Oxidant Compressor | | |
| Polytropic Efficiency, percent | 87 | 86 |
| Discharge Pressure, psia | 73.5 | 55.0 |
| Flow Rate, lb/hr | 867,852 | 650,899 |
| Steam Turbine Drive | | |
| Efficiency, percent (overall) | 80 | 78 |
| Steam Inlet Temperature, $^{o}F$ | 1,000 | TBD |
| Steam Inlet Pressure, psia | 395 | TBD |
| Steam Discharge Pressure, psia | 1.23 | TBD |

### 2.5.2 MHD Power Train

The MHD Power Train is the electric power generatng system of the ETF topping cycle. It consists of four major subsystems:

Combustor

MHD Generator

Inverter

MHD Control

A detailed system design description of the MHD Power Train (SDD-502) is contained in Section 5.5, and includes modes of operation system interfaces, operational parameters, and detail drawings. Reference to particular detail drawings is noted in the following subsystem descriptions. Integration of this system into the ETF design is described in Section 5.2 and is shown on the heat and mass balance diagram, 8270-1-540-314-001, found in Appendix 2A. The superconducting magnet is integrally involved in producing a magnetic field for the MHD generator, and is discussed separately in Section 2.5.3.

#### 2.5.2.1 Combustor Subsystem

The combustor subsystem generates the thermal energy for the ETF from the pressurized combustion of coal using a preheated, oxygen enriched oxidant. It generates plasma conditions required for dc electric power production in the MHD channel and rejects a large fraction of the slag content of the coal. The combustion process occurs at a fuel rich stoichiometric ratio to provide a reducing atmosphere for $NO_x$ control. Potassium seed is injected into the combustor plasma to provide the required plasma electrical conductivity and to capture sulfur released in the combustion of the coal.

The subsystem consists of a two-stage combustion chamber, coal, oxidant, and seed injectors, plasma duct, a nozzle, slag removal equipment and installed instrumentation. See SDD-502 (Drawing No. SDD-1200). Operating parameters are shown on Table 2-8. Components are cooled by the high pressure boiler feedwater system to maintain the metal surfaces below allowable working temperature and working stress levels. All wall surfaces exposed to the combustion gases are designed to be slag coated to reduce heat loss and protect the surfaces. Voltage isolation is provided between the subsystem and all external connections and mountings to prevent electrical currents from being induced by the Hall potential. The overall subsystem is designed for minimum pressure drop and heat loss to the containment walls. Subsystem mounting arrangement (Drawing No. SDD-1102) is designed to support the thrust of the exiting plasma jet, to avoid loading the channel/diffuser by thermal expansion, and to permit disconnecting the plasma duct from the nozzle for channel removal. The combustor subsystem is constructed with non- magnetic materials.

TABLE 2-8
COMBUSTOR SUBSYSTEM OPERATING PARAMETERS

| | | |
|---|---|---|
| A. | Thermal input, MWt | 531.9 |
| B. | Fuel | Coal, Montana Rosebud, 5% moisture as fired |
| | 1. Flowrate, lb/hr | 165,622 |
| | 2. Inlet pressure, psia (nominal) | 71 |
| | 3. Inlet temperature, °F | 150 |
| C. | Oxidant | Air enriched with oxygen to a total of 30% by volume |
| | 1. Flowrate, lb/hr | 867,852 |
| | 2. Inlet pressure, psia (nominal) | 71 |
| | 3. Inlet temperature, °F | 1,100 |
| D. | Seed | Potassium, 1% nominal of channel flow |
| | 1. Flowrate, lb/hr | 21,230 |
| | 2. Inlet pressure, psia (nominal) | 71 |
| | 3. Inlet temperature, °F | 150 |
| E. | Slag Rejection | 65% (min.) |
| | 1. Flowrate, lb/hr | 11,523 |
| F. | Nozzle Outlet | |
| | 1. Stagnation temperature, °F (nominal) | 4380 |
| | 2. Static temperature, °F (nominal) | 4140 |
| | 3. Stagnation pressure, psia (nominal) | 58 |
| | 4. Static pressure, psia (nominal) | 37 |
| | 5. Mach number | 0.9 |
| | 6. Plasma velocity, ft/sec (nominal) | 2,650 |
| G. | Operating Life | |
| | 1. Combustor, hours | 8000 |
| | 2. Slag rejection equipment, years | 30 |
| H. | Heat Loss (combustor and nozzle) | 25 MWt |
| I. | Coolant | Treated high pressure boiler feed water |
| | 1. Flowrate, lb/hr | 1,070,992 |
| | 2. Inlet temperature, °F | 530 |
| | 3. Outlet temperature, °F | 529 |
| | 4. Inlet pressure, psia (nominal) | 2,100 |

2.5.2.1.1 Combustion Chamber

The combustion chamber is a two stage unit designed to have stable combustion at full and part power, required turndown ratio*, high combustion efficiency (carbon conversion) and continuous slag rejection. The fuel, oxidant and seed injectors are designed and located in the combustion chamber to provide the injection angle and distribution needed for thorough mixing and swirl. Adequate mixing ensures slag rejection and homogeneous plasma and temperature cross-sectional profile at the combustor discharge. Coal is injected in a fluidized state with a carrier gas. Slag rejection and gasification of the coal occurs in the first stage in a solid/gas reaction. Fuel and oxidant are injected at a fuel rich stoichiometric ratio (60 percent) chosen to be adequate to gasify the coal, yet limit the temperature to a level which will not vaporize the slag. Additional oxidant is injected into the second stage for completion of combustion (gas/gas reaction) at 90 percent stoichiometry. Seed injection and ionization occur in the second combustor stage producing the plasma required by the MHD channel.

2.5.2.1.2 Plasma Duct

The plasma duct is the removable portion of the second stage combustor and transports the plasma flow from the combustor discharge to the nozzle inlet. The length of the duct will be the minimum necessary to provide accessibility between the combustion chamber and the nozzle for removal of the MHD channel. The duct is designed with flanged connections.

2.5.2.1.3 Nozzle

A convergent nozzle accelerates the plasma flow from near zero velocity at the combustor to that required for the operation of the MHD channel. It is designed with flanged connections and is constructed with a square gas dynamic cross section.

2.5.2.1.4 Slag Removal Equipment

Slag removal equipment is designed for operation at combustor pressure and consists of slag collection and quench tanks and interconnecting piping and isolation valves. Slag from the combustor flows into the tank-quench water and is broken up by high quench stresses. A crusher at the bottom of the tank reduces the slag pieces to slurry consistency for ease of transport. Electrical isolation will be provided at the downstream flanges of the 1st and 2nd stage slag collection tanks.

2.5.2.2 MHD Generator Subsystem

The MHD generator is the heart of the MHD power train system. The design and operating parameters are shown in Table 2-9. Channel parameters and magnetic field profile are selected on the basis of maximum plant efficiency at

*"Turndown ratio" is the ratio of full load to part load operating level capability; e.g., 2 to 1 indicates the ability to operate down to 50 percent load.

TABLE 2-9
MHD GENERATOR DESIGN AND OPERATING PARAMETERS

| | | | |
|---|---|---|---|
| A. | Channel Inlet | | |
| | 1. Stagnation temperature, °F (nominal) | | 4,380 |
| | 2. Static temperature, °F (nominal) | | 4,140 |
| | 3. Stagnation pressure, psia (nominal) | | 58 |
| | 4. Static pressure, psia (nominal) | | 37 |
| | 5. Mach number | | 0.9 |
| | 6. Plasma velocity, ft/sec (nominal) | | 2,650 |
| | 7. Mass flow, lb/hr | | 1,048,569 |
| | 8. Heat-rejection from MHD Channel, MWt (nominal) | | 23 |
| B. | Channel Outlet/Diffuser Inlet | | |
| | 1. Stagnation pressure, psia (nominal) | | 14.0 |
| | 2. Static pressure, psia (nominal) | | 9.0 |
| | 3. Mach number | | 0.88 |
| | 4. Velocity, ft/sec (nominal) | | 2,440 |
| | 5. Stagnation temperature, °F (nominal) | | 3,760 |
| | 6. Static temperature, °F (nominal) | | 3,500 |
| C. | Channel active length, ft (nominal) | 40.0 | |
| D. | Channel overall length, flange to flange, ft (nominal) | 50.0 | |
| E. | Channel cross section, square geometry ft x ft | | |
| | 1. Entrance | 2.04 x 2.04 | |
| | 2. Exit | 4.66 x 4.66 | |
| F. | Channel operational life, minimum, hours | 2,000 | |
| G. | Magnetic flux density, peak, teslas | 6 | |
| H. | Diffuser outlet | | |
| | 1. Flowrate, lb/hr | | 1,048,569 |
| | 2. Pressure, psia | | 13.0 |
| | 3. Temperature, °F (nominal) | | 3,500 |
| I. | Diffuser pressure recovery coefficient | 0.46 | |
| J. | Dffuser operational life, years | 30 | |
| K. | Heat rejected from diffuser walls, MWt (nominal) | 26 | |
| L. | Diffuser length, ft (nominal) | 40 | |
| M. | Gas dynamic cross-section | | |
| | Inlet, $ft^2$ (nominal) | 22 | |
| | Outlet, $ft^2$ (nominal) | 64 | |

conditions minimizing compressor power, channel heat loss, and oxygen enrichment requirements. These criteria result in a magnetic field having a 6 tesla* peak and a channel active length of 12.1 meters from 4 teslas at the inlet and to 3.5 teslas at the exit end. The overall channel length is 16 meters. Channel inlet and outlet flanges are located in a magnetic field of less than 0.5 teslas to minimize the destructive effect of circulating currents.

The MHD generator subsystem (Drawings SDD-1101 and SDD-1102) consists of the MHD channel, consolidation circuitry, and a diffuser. Plasma flows from the nozzle through the MHD channel producing dc electric power by the interaction of plasma with the magnetic field. Hot exhaust gas from the channel flows to the diffuser which reduces velocity and provides pressure recovery. The diffuser is designed to tailor the outlet pressure and velocity to the HR/SR inlet requirements. The dc electric power produced in the channel is consolidated and organized by the consolidation circuitry and is provided to the inverter subsystem for conversion to ac power.

The MHD channel with support structure is mounted in the warm bore of the 6 tesla superconducting magnet (Drawings SDD-1300 and SDD-1301). Periodic removal and replacement of the channel is anticipated. This requires provisions for disconnecting the channel from the combustor and diffuser, and for pull space and handling equipment.

2.5.2.2.1 MHD Channel

The channel is designed to the specified 6-tesla peak-magnetic field profile. Its active section (12.1 meters) incorporates 704 electrode pairs and is defined as that portion of the channel lying between the field values of 4 teslas at the entrance and 3.5 teslas at the exit. Within the active section, the channel will be of the diagonally connected Faraday type which incorporates segmented electrode walls and bar type insulator wall elements.

These electrodes and wall elements are copper, water cooled, and are electrically insulated from each other. Anode electrodes are capped with platinum. Electric power will also be extracted from the inlet and outlet sections lying between the active section and the flanges. These sections will be of the diagonal window frame type and be fabricated of copper with provisions for water cooling.

The channel will be cooled with high purity water from the boiler feedwater system. Each electrode and wall element incorporates a nickel plated coolant passage and inlet and outlet coolant connections. A water manifolding arrangement is provided for inlet and discharge coolant water from each electrode and wall element. Flexible hose is installed between the channel water coolant connections and the water manifolds for electrical isolation.

* One tesla is a magnetic induction or magnetic flux density equivalent to $1 \times 10^4$ gauss.

The channel electrodes and insulators are assembled within a pressure vessel fabricated from G-11 glass/epoxy composite which also provides box beam structural support. An external structure (Drawing SDD-1301) supports the channel, coolant water manifolding and the power take-off electric cables in the magnet warm bore. This assembly is designed for rapid installation and removal of the channel. A separate electric power take-off cable is connected to each electrode terminal. Due to the large number of electrodes, the cables will be bundled to minimize space packaging requirement. Approximately 30 percent of the power take-off cables will be led out at channel inlet and the remainder at the channel outlet. Electric connectors will be used for connecting the power take-off cables to the consolidation circuitry.

2.5.2.2.2 Consolidation Circuitry

The electric consolidation circuitry matches the raw electric power output from the MHD channel to the input requirements of the inverters. Electric power from groups of electrodes taken at many different source voltages and currents are combined and converted into a few stable direct current sources. The consolidation circuitry acts to control the channel loading, regulate electrode currents within established limits and stabilize the MHD channel operation. The consolidation circuitry is designed to provide Faraday loading of the channel electrodes while diagonally connecting them to take advantage of the Hall potential and thus provide power at the highest possible voltage (see Ddrawings SDD-1501, SDD-1502, SDD-1503, and SDD-1504).

2.5.2.2.3 Diffuser

The diffuser is installed between the channel outlet and HR/SR inlet. The function of the diffuser is to decelerate the nearly sonic hot exhaust gases from the channel before exhausting into the HR/SR at essentially ambient pressure. The diffuser is designed for operation with slag coated walls and is constructed of non-magnetic materials. Diffuser size and divergence angle are selected for maximum pressure recovery factor. The diffuser design incorporates two removable sections required for channel removal. The diffuser cooling is designed for steam generation and the cooling circuits are integrated with the HR/SR boiler (drawings SDD-1400, SDD-1401, and SDD-1402).

2.5.2.3 Inverter Subsystem

Power from the channel is extracted using one end-to-end connection, and five additional extraction points for a total of 89 MWe. A line-commutated system using both 20 MW and 4 MW inverters will invert the dc power taken from the electrodes to ac power for delivery to the 34.5 kV ac bus. Specific filters will reduce the 5th, 7th, 11th, and 13th harmonics and a combined filter system will be used for all higher harmonics. Each inverter has bypass protection in the event of failure and dc breakers are installed in the event an entire line of inverters fail. The inverter building is forced air cooled to reduce volume and improve reliability. Details of this subsystem are provided in SDD-505, in Section 5.5.

### 2.5.2.4 MHD Control Subsystem

The MHD control subsystem controls those energy conversion processes within the MHD channel which are directly involved with regulating two-terminal dc power and producing the plasma flow rates required by power demand. This subsystem controls and regulates combustor operation and plasma conductivity by controlling coal, oxidant and seed input to the combustor for the required power level demand. The subsystem controls the MHD channel electrical load through sensing and measurement of the electrode power take-off currents and voltages, and the switching and modulation of active electrical control elements within the consolidation network. It also acts to regulate the flow of two terminal dc electrical power into the inverter and to connect or disconnect itself from the inverter as required (Drawing SDD-1500).

This subsystem informs the supervisory control system (facility control system) of the status of the MHD power train and detects abnormal operation. It stabilizes operation of the power train within its operational range through coordinated control of the combustor, generator, and electrical consolidation circuitry. The subsystem is designed to protect the MHD power train system. In the event of abnormal operation, the control subsystem will initiate corrective action within the required response time.

### 2.5.3 Magnet

The Magnet System involves the use of advanced superconducting magnet technology to provide the magnetic field required by the MHD channel for power generation. The system consists of the magnet and accessory equipment as contained in the following subsystems and shown on Figure 2-4:

- Magnet assembly
- Cryogenic support equipment
- Power supply and dump equipment
- Protection/control circuit
- Vacuum pumping equipment
- Roll aside drive equipment

The magnet assembly consists of liquid-helium-cooled superconducting coils protected by a thermally insulated enclosure with the warm bore extending horizontally through the center. The outline dimensions of the magnet assembly and the dimensions of the cavity are shown on drawing D4441 of SDD-503, Section 5.5.

The cryogenic support equipment consists of a helium refrigerator/liquifier/compressor assembly, storage tanks, heat exchangers, transfer lines, and controls required for magnet cool-down and maintaining the low temperatures required by the magnet coils. This equipment will maintain these low temperatures for extended periods of time.

The power supply and dump equipment consists of a rectifier-type dc power supply, dump resistors, circuit-breaker and controls. This equipment is required for charging the magnet, maintaining it at the desired field strength, and discharging it under both normal and emergency shutdown conditions.

Protection and control equipment consists of instrumentation to detect abnormal conditions in the magnet's superconducting coils and controls to automatically activate protective measures. Also included are instruments and controls to permit remote monitoring and manual control of major functions of the magnet and associated equipment at the main control room.

Vacuum pumping equipment consists of diffusion and mechanical pumps for evacuating the magnet vacuum jacket during initial magnet cooldown. This system will also remove from the jacket any helium leakage that may occur from the coil container during magnet operation.

The roll aside drive equipment consists of hydraulic cylinders for moving the magnet on its tracks and the associated hydraulic pump package.

The magnetic field produced in the region surrounding the magnet is a hazard to personnel and equipment. This hazard exists only when the magnet is charged. A fringe magnetic field extends outward from the charged magnet as far as 270 feet, at which distance the magnetic induction level will be 0.0005 tesla (5 gauss). Within a perimeter formed by a varying distance of 82 feet by 100 feet from the magnet (0.01 tesla), sensitive equipment is

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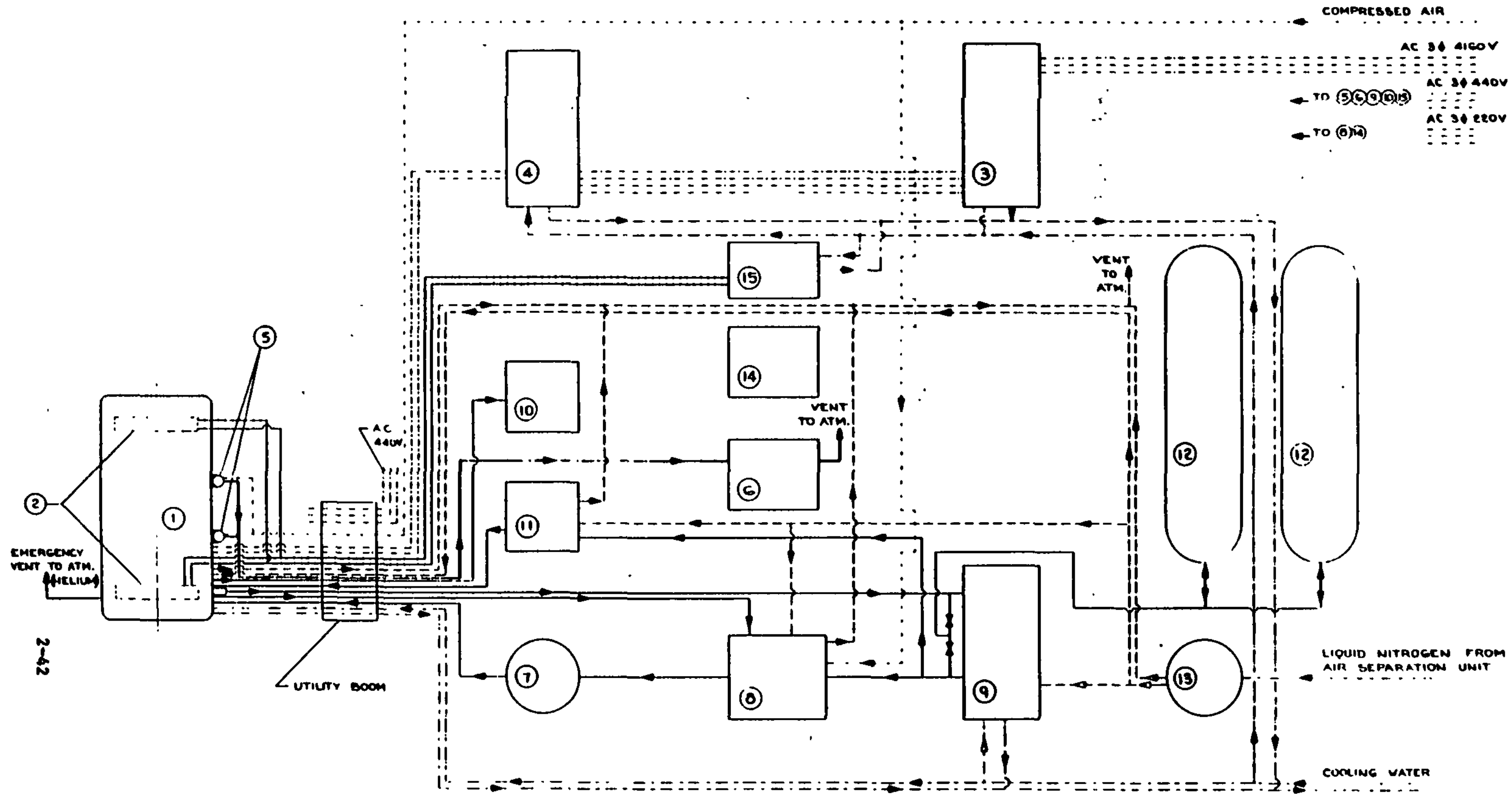


| ITEM NO | DESCRIPTION |
|---|---|
| 1 | MAGNET |
| 2 | HYDRAULIC ACTUATORS |
| 3 | POWER SUPPLY PACKAGE |
| 4 | DUMP RESISTORS |
| 5 | DIFFUSION PUMPS |
| 6 | VACUUM PUMP PACKAGE |
| 7 | LIQUID HELIUM STORAGE TANK |
| 8 | LIQUIFIER / REFRIGERATOR |
| 9 | HELIUM COMPRESSOR PACKAGE |
| 10 | WARM-UP HEAT EXCHANGER |
| 11 | COOL-DOWN HEAT EXCHANGER |
| 12 | GASEOUS HELIUM STORAGE TANK |
| 13 | LIQUID NITROGEN STORAGE TANK |
| 14 | UTILITY VACUUM PUMP PACKAGE |
| 15 | HYDRAULIC PUMP PACKAGE |

**LEGEND**

- ———— = HELIUM
- – – – – = NITROGEN
- – · – · = WATER
- – ——— = VACUUM
- ——— = HYDRAULIC FLUID
- · · · · = COMPRESSED AIR
- – · – – = ELECTRICITY

REFERENCE DRAWINGS

- D-4450 GENERAL ASSEMBLY
- D-4445 PLAN AND ELEVATION
- D-4452 DIAGRAM, HELIUM SYSTEM
- D-4453 DIAGRAM, NITROGEN SYSTEM

**FIGURE 2-4**
**MAGNET SYSTEM**

| REV | DESCRIPTION | BY | DATE | APPD |
|---|---|---|---|---|
| A | REDRAWN WITH CHANGES. TITLE WAS ETF MAGNET SYSTEM-SYSTEM DIAGRAM (SCHEMATIC) | [illegible] | 2-11-81 | [illegible] |

TITLE: MHD-ETF 200 MWe POWER PLANT MAGNET SYSTEM

SYSTEM DIAGRAM (SCHEMATIC)

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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D 4456 A

excluded and the length of time that approved personnel are allowed to remain in the area is also limited. This exclusion limit is an interim design value and is subject to future change.

The superconducting windings must be at liquid helium temperature for operation. Initially, the windings must be cooled from room temperature to liquid helium temperature, a process requiring up to 30 days. After cooling to design temperature, the magnet can be charged and discharged relatively quickly. It is planned that the magnet will be kept cold continuously for long periods of time, being allowed to warm up only in the event of a facility shutdown of several months duration or some other unusual circumstance.

Emergency shutdown of the magnet is accomplished by the activation of circuit breakers in the dc power supply system, causing all magnet current to flow through a water-cooled resistor package. The emergency discharge time from full field to 0.04 full field (current 1000 A) is less than 1 minute. Discharge to 0 field is less than 3 minutes.

Both manual and automatic activation of the circuit breaker are provided. Manual operation will be by means of an emergency push-button at the main control station of the facility. Automatic operation will be actuated by a quench protection system and/or other sensors as described in Section 5.5.

### 2.5.3.1 Magnet Assembly

The magnet windings consist of a pair of saddle-shaped coils, each made of 572 turns of superconducting, cable-type conductor. The turns are insulated from each other and are individually supported by a substructure consisting of stacks of fiber glass-plastic plates notched to receive the conductors. The windings are designed to produce the peak on-axis field of 6 teslas and the field profile along the axis as required for channel performance, with uniform field throughout cross-sections. The design current density in the conductor is constant throughout and is conservatively low ($1.42 \times 10^7$ $A/m^2$). The field profile and bore dimensions are shown on Figure 2-5.

The winding of each coil is made up of 26 saddle-shaped layers, each layer containing 22 turns. Through-bolts are used to clamp the winding and substructure in place in the coil containers. After the windings are installed, a cover plate is welded in place. A spring plate between cover and winding and spring-shims at the inner wall of the coil container, are provided to compress the winding within the coil container, thereby minimizing conductor motion during charging.

Each coil, with its substructure is enclosed in a heavy-walled, stainless steel containment vessel and immersed in liquid helium. The substructure incorporates a system of passages which ensure access for helium coolant to all parts of the windings. This substructure is also designed to support individual conductors against both gravity and magnetic forces and to transmit the total accumulated forces to the walls of the containment vessel. These forces are then transmitted through these walls to the main force containment structure which is external to the containment vessel.

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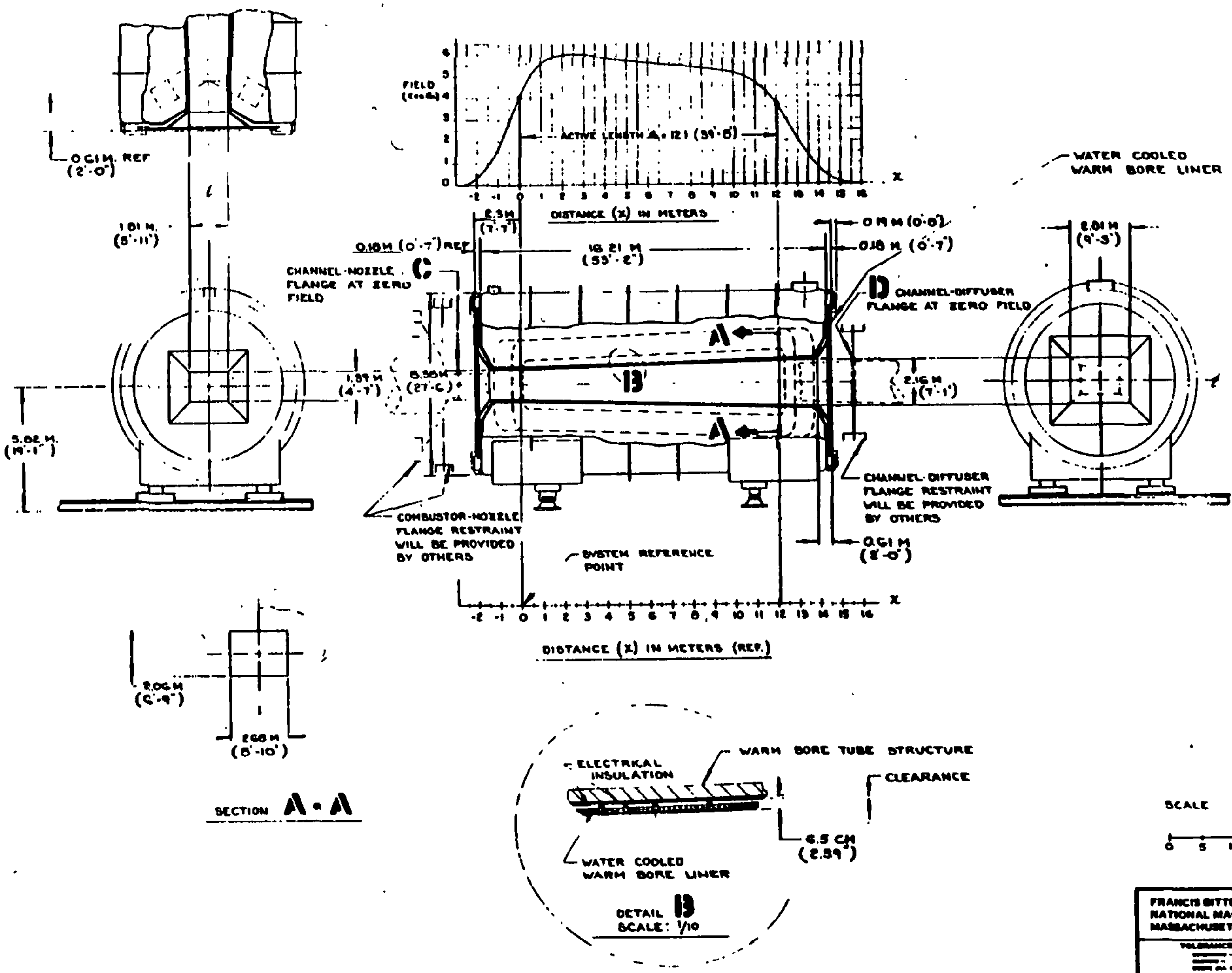


REFERENCE DRAWINGS

D-4441 OUTLINE
D-4450 SHT. 1, 2, 3, & 4 GENERAL ASSY

FIGURE 2-5
MAGNET SYSTEM

SCALE

0 5 10 15 20 25

(FEET)

| REV | DESCRIPTION | BY | DATE | APPD |
|---|---|---|---|---|
| B | REDRAWN WITH CHANGES TITLE WAS "ETF-MAGNET FIELD PROFILE & BORE DIMENSIONS" | | 2-13-81 | |
| A | REDRAWN & REVISED WAS C-4439 | | 11-13-80 | |

TITLE: MHD-ETF 200 MW POWER PLANT MAGNET SYSTEM

FIELD PROFILE AND BORE DIMENSIONS

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SCALE 1/100 D 4439 B

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The superconducting cable consists of wires made of two materials, namely, multi-filament NbTi/Cu monolithic wire and OFHC copper wire. The critical current for the cable is 28,700 A at -451.5°F with a ratio of operating to critical current of 0.85. The cable conductor has been designed to be stable relative to the disturbances expected during operation. This implies that conductor sections which are driven out of the superconducting state and into a normal condition are sufficiently well cooled to allow recovery to a superconducting condition.

The total weight of the magnet is 2,000,000 lb with a length of 54.4 feet. A unique design feature of the ETF magnet is its ability to roll 34 feet to an open area for removal and replacement of the channel. Fringe fields from the magnet may have adverse effects on personnel and equipment and as a result, restrictions have been applied to the placement of auxiliary equipment and the access of personnel.

2.5.3.2 Cryogenic Support Equipment

The supporting cryogenic equipment for the superconducting magnet includes:

- Helium refrigerator/liquifier
- Helium compressor package
- Liquid helium storage dewar
- Gaseous helium storage tanks
- Liquid nitrogen storage dewar
- Cool-down heat exchanger
- Warm-up heat exchanger

The helium refrigerator/liquifier incorporates a precooled expansion engine cycle using normal boiling liquid nitrogen as the precoolant. Based on a rated capacity of 33 gallons per hour helium liquifaction (gas returned at 80°F) and 250 watts refrigeration (gas returned at approximately -451.5°F) the input power requirement for the refrigerator/liquifier system will be approximately 500 kW. Equipment includes screw-type compressors, turbine-type expansion engines and a large storage dewar to store the liquid helium produced. Liquid helium is transferred to the magnet as required to maintain the operating level of liquid in the magnet winding containment dewar. Transfer is accomplished by pressurization of the storage dewar and is controlled automatically by a valve in the transfer line.

A portion of the helium boil-off from the magnet dewar is utilized to cool the vapor-cooled power leads. This portion is raised to room temperature in passing through the leads and is then returned to the helium compressor suction. The balance of the helium boil-off is returned at near liquid helium temperature, via vacuum insulated piping, to the refrigerator/liquifier.

The liquid nitrogen system, consisting of a liquid nitrogen storage dewar, pressurizing coils, piping and controls, is provided for three purposes: (1) to provide cooling for the thermal shield in the magnet dewar, (2) to provide coolant for the closed-loop gaseous helium circuit (including cool-down heat exchanger) used for initial cool-down of the magnet, and (3) to provide precooling for the helium refrigerator/liquifier.

During operation of the power plant, make-up liquid nitrogen is supplied to the liquid nitrogen storage tank from the Air Separation Unit (ASU) which provides oxygen enrichment for the topping cycle. When the plant and ASU are not in operation, make-up liquid nitrogen is supplied by bulk transport from commercial suppliers, directly to the storage dewar.

The liquid nitrogen storage dewar is pressurized to permit transfer of liquid to the magnet thermal shield, refrigerator/liquifier, and cool-down heat exchanger. Nitrogen gas vented from these items of equipment is vented to atmosphere via a collection system. The estimated liquid nitrogen consumption of the magnet system under normal operating conditions is 56 gallons per hour.

#### 2.5.3.3 Power Supply and Dump Equipment

Power supplied to the magnet will be direct current that is obtained from the plant's medium voltage ac system via a step down transformer. The transformer secondary windings will feed solid state diode and silicon controlled rectifier bridges necessary to produce dc at the required current and voltage levels.

The power supply system incorporates controls to permit energizing the magnet at preselected constant voltage and to permit operation in a constant current mode upon reaching the desired operating magnetic field. Normal discharge of the magnet is through the power supply. Emergency (fast) discharge of the magnet is accomplished by using a system of dc switches to disconnect the rectifier from the magnet, thereby causing the magnet to discharge through water-cooled resistors. The design covers a fault or disturbance that initiates a quench (reversion to resistive state) in the superconducting windings; i.e., the emergency discharge system is capable of discharging the magnet fast enough to prevent damage by overheating.

#### 2.5.3.4 Protection/Control Circuit

The protection/control circuitry protects against adverse effects of magnet system malfunction and permits remote monitoring and control of major functions of the magnet and associated equipment at the station control room.

The major elements of protection/control circuitry are:

1. Magnet quench detection system

2. Magnet liquid helium level monitoring system

3. Vacuum monitoring system

4. Vapor-cooled power lead temperature monitoring system

5. Automatic warning/emergency shutdown system responsive to critical monitored parameters

6. Remote magnet charge/discharge controls

Requirements include:

1. The quench detection/automatic shutdown system shall initiate emergency discharge at a short enough interval after appearance of local winding quench to ensure that no part of the winding is damaged by overheating.

2. The lead temperature monitoring system shall initiate emergency shutdown in time to prevent damage to leads by overheating, under conditions including loss of coolant to leads.

2.5.3.5 Vacuum Pumping Equipment

The vacuum system for the magnet dewar and cryogenic plant will include a combination mechanical roughing pump and oil diffusion pump to establish a vacuum in the low $10^{-4}$ torr range. System cryopumping will then reduce the vacuum to the operating level which will be $10^{-5}$ torr.

### 2.5.4 Heat Recovery/Seed Recovery (HR/SR)

The HR/SR includes the radiant boiler, superheaters, reheaters, oxidant heater, high temperature economizer, and electrostatic precipitator. Its multi-functions include:

Generating and superheating steam

Seed recovery

Preheating the oxidant

Capturing particulates

Heating feedwater

Providing flue gas residence time at high temperatures for chemical reactions to proceed to the required degree of equilibrium.

Baseload operating points for the HR/SR subsystems are shown on the System Heat and Mass Balance Diagram 8270-1-540-314-001. Figure 2-6 is a schematic illustration of the HR/SR.

#### 2.5.4.1 Boiler

Boiling of the feedwater takes place in the vertical water-tube walls in the first section of the radiant boiler chambers. The initial chamber also serves as a NOx control furnace. This is done by lining the tube walls with a refractory to lessen the rate of temperature change of the gas and also provide a time delay until the gas reaches the 'freeze' temperature for NOx of about 2,900$^{o}$F. Since there exists a reducing atmosphere in this region, the refractory also serves as a corrosion barrier between the gas and the water walls. The mixture of steam and water rises to the steam drum from which water is recirculated and steam continues to the superheater.

Downstream of the NOx control furnace (see Subsection 2.5.6.2.2) a second section of the radiant boiler has bare metal tube walls. The reduced combustion rate combined with the high heat transfer to the bare walls prevents high temperature which could increase NOx generation. The boiler assembly system includes the slag, ash and spent seed collector at the bottom of the boiler chambers. This collector consists of hoppers which collect the slag and direct it into quenchers which freeze and break it into small fragments. These fragments are discharged to the seed and slag management systems (Sections 2.5.6.4 and 2.5.6.5).

#### 2.5.4.2 Superheater

Steam formed in the boiler walls is separated from the two-phase mixture in the drum and is superheated in the convective passes and radiant panels of the superheater. Steam leaving the superheater at 1,005$^{o}$F and 1,910 psia is piped to the main steam turbine.

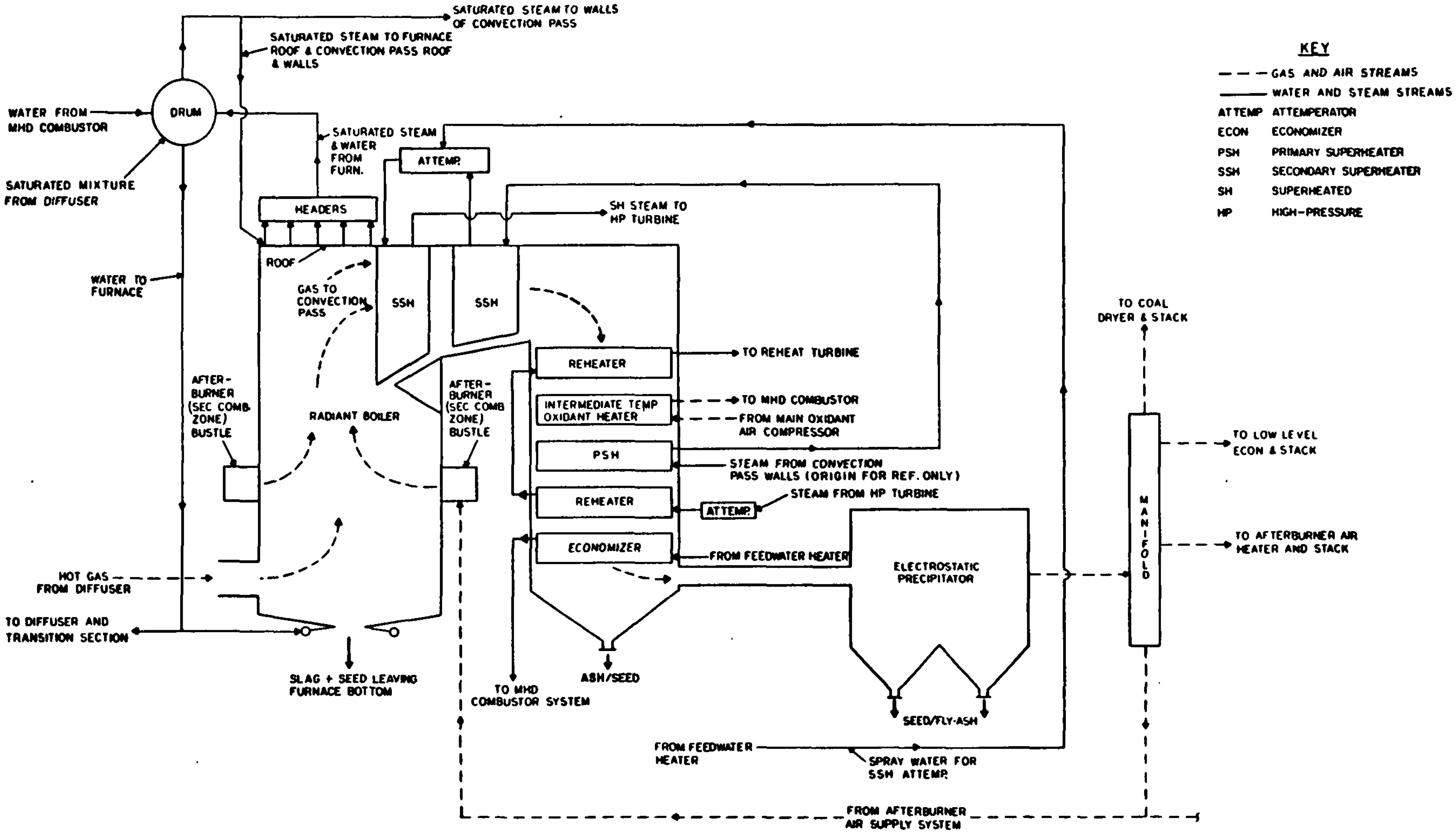


FIGURE 2-6
HEAT RECOVERY/SEED RECOVERY SYSTEM

A spray attemperation unit is available to prevent overheating of final steam. Water for attemperation is piped from the feedwater system to the inlet of the final stage of superheat.

2.5.4.3 Reheater

Steam discharged from the high pressure turbine, except for that extracted or lost through leakage, is piped back to the reheater where its temperature is raised to 1000°F. Spray attemperation is provided for the reheat steam entering the second stage reheater to control reheater outlet steam temperature.

2.5.4.4 Oxidant Heater

The oxidant heater is a gas-to-gas heat exchanger containing a convective heater section and a radiant heater section. The oxidant, 30 mol percent oxygen, enters the heater at 430°F and exits at 1,100°F to the combustor.

2.5.4.5 High Temperature Economizer

The high temperature economizer is a gas-to-water heat exchanger located in the final pass of the steam generation system. Feedwater is heated by the flue gas. Flue gas temperature at exit is maintained at the 480°F level since, after particulate removal by an ESP (Section 2.5.4.6), over 40 percent of the flue gas is recycled to the pulverizers for drying and transport of the coal fines.

2.5.4.6 Electrostatic Precipitator (ESP)

The ESP is designed to operate near the 500°F level and the collector area is sized to handle finer particulates than occur in conventional power plants.

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### 2.5.5 Steam Power Systems

The MHD-ETF design utilizes topping cycle heat recovery equipment (HR/SR) to transfer the MHD Power Train exhaust gas waste heat into steam generation. The generated steam is used in a conventional Rankine turbine generator "bottoming" cycle to produce additional electric power. Part of the steam is used for turbine drives to power auxiliary equipment. The chosen cycle features reheat of the steam (in the HR/SR), regenerative feedwater heating, a condensing low pressure turbine, and cooling towers as a heat sink. A schematic diagram of the cycle is shown on Figure 2-1, following Section 2.1.2.5. Steam and water flow conditions may be found on the heat and mass balance diagram, 8270-1-540-314-001 in Appendix 2A.

Main steam generated in the HR/SR passes through a high pressure turbine and returns to the HR/SR for reheating. The steam then flows through a reheat, or intermediate pressure, turbine, and then through a low pressure turbine which exhausts into a water cooled condenser. The condensed steam, or condensate, is pumped through demineralizers, a deaerator, and then through regenerative feedwater heaters before returning to the MHD cycle as a coolant. The water ultimately returns to the boiler drum of the HR/SR to complete the cycle.

#### 2.5.5.1 Main and Reheat Steam

The main steam system conveys steam at design conditions, 1,815 psia and 1000°F, to the high pressure turbine. Reheat steam is conveyed from the high pressure turbine exhaust, through the reheater where its temperature is raised to 1000°F, and then to the intermediate pressure turbine. Reheat steam is also supplied to the steam turbine drives for the ASU compressor, oxidant compressors, and the boiler feed pumps. Flow loops and arrangements are shown schematically on Fluid System Diagram 8270-1-501-302-011.

##### 2.5.5.1.1 Flow Description

Main steam flow at base load is 1,071,000 pounds per hour at 1,910 psia and 1005°F leaving the superheater. Main steam piping pressure drop will be limited to a total of 96 psi with velocities limited to 15,000 feet per minute. Superheat steam temperatures are controlled by a spray system from boiler feed pump discharge water to desuperheaters located between the primary and secondary superheaters.

Reheat steam pressure drop is restricted to 44 psi with loss in the cold reheat piping 7 psi of the 44 psi total. Velocities in cold and hot reheat piping are limited to 15,000 feet per minute. Extraction steam to feedwater heaters 4A and 4B is supplied from a branch connection off the cold reheat piping.

##### 2.5.5.1.2 Major Equipment

Major equipment includes high pressure, intermediate pressure, and low pressure turbines, generator, and mechanical drive steam turbines. Table 2-10 summarizes the performance of these components and the performance of the superheater and reheater of the HR/SR system.

## TABLE 2-10
## MAIN AND REHEAT STEAM SYSTEM EQUIPMENT

| Item | System Design Description | Fluid System Diagram |
|---|---|---|
| Compressor drive turbines | Oxidant Supply | 1-FS-820 |
| Feedwater pump drive | Boiler Feedwater | 8270-1-521-302-081 |
| Steam bypass | Steam Bypass and Startup | 8270-1-504-302-031 |
| Superheater and Reheater | HR/SR | 8270-1-501-302-011 |

1. Turbine Generator

| | |
|---|---|
| Type | Tandem compound, two casing, two flow exhaust, single reheat |
| Rating, MW | 128 |
| Speed, rpm | 3,600 |
| Inlet pressure, psi | 1,815 |
| Inlet temperature, °F | 1,000 |
| Reheat temperature, °F | 1,000 |
| Throttle flow, lb/hr | 1,070,992 |
| Exhaust pressure, in. Hg | 2.0 |
| Number of extractions | 4 |

2. Superheater

| | |
|---|---|
| Flow, lb/hr | 1,070,992 |
| Pressure, psi | 1,910 |
| Temperature, °F | 1,004.9 |

3. Reheater

| | |
|---|---|
| Flow, lb/hr | 986,470 |
| Inlet pressure, psi | 451 |
| Inlet temperature, °F | 649.3 |
| Outlet pressure, psi | 429 |
| Outlet temperature, °F | 1,001.2 |

### 2.5.5.1.3 Modes of Operation

1. Startup

During the startup sequence, mismatches occur in component temperatures. If significant temperature differences exist between the HR/SR, steam turbine and the steam transfer piping, thermal stresses exist that are capable of damaging the equipment. To eliminate this possibility, conditions (e.g., temperatures) compatible with normal operation have to be achieved by the startup procedures. The procedure that will ensure satisfactory startup includes the following steps.

a. Cleanup of feedwater cycle to acceptable purity conditions.

b. HR/SR filled and vented to startup drum level.

c. Operational boiler feed, condensate, and circulating water systems.

d. The main steam turbine is placed on turning gear and is rolling prior to admitting gland sealing steam and establishing a vacuum.

e. Auxiliary Steam System is functional for initial deaeration, turbine seals, and for system warmup.

f. Main condenser vacuum is established as low as possible, but no greater than 5.0 inches Hg.

g. When main steam pressure reaches 200 psig minimum, the stop valve bypasses are opened to initiate prewarming the HP turbine casing, reducing turbine thermal stresses. This is done while the turbine is on turning gear. Throughout the turbine prewarming operation, turbine casing metal and differential temperatures are monitored, recorded and maintained according to the limits set by the turbine manufacturer.

h. During HR/SR warmup operation, boiler blowdown is monitored to check acceptable solids concentration levels. Steam piping is warmed, with all drains opened, as steam pressure increases.

i. The following turbine metal temperatures are recorded prior to initial roll off turning gear:

   First stage shell inner surface
   First stage shell outer surface
   First reheat bowl inner surface

j. The turbine is rolled off turning gear when the inlet steam conditions at the turbine throttle valves are approximately 600 psig with 100°F of superheat. This will provide optimum uniform heating and differential expansion rates dictated by the turbine manufacturer.

k. The turbine is accelerated to a rotor warming speed and maintained until the unit is satisfactorily pre-warmed. Acceleration may then continue to 3,600 rpm, and the turbine synchronized and loaded.

2. Normal Operation

The normal load range of the overall plant is categorized as base load with a small percentage part load operation below 75 percent. The plant is capable of operating satisfactorily and with no special operator action in the event of small load changes. During normal operation the overall plant is controlled and monitored from the main control room. Should the load go below 75 percent, administrative action would be required to decide: What percentage of the load the topping side or bottoming side would share; whether the bypass system should be initiated; whether the turbine and steam piping drains are to be opened; or if the unit should be tripped.

The normal load range of the main and reheat steam system is categorized as base load with a small percentage part load operation below 75 percent. Should the unit be operated below this level, administrative action will be provided to ensure that drain valves will be opened at 25 percent and lower load ratings. Also the steam bypass system may be activated at 50 percent or lower steam flow to the main turbine. The system is capable of operating satisfactorily and without special operator action in the event of load change on the unit. During normal operation, the system is controlled and monitored from the main control room.

3. Shutdown

For operator-initiated shutdown, the unit load is reduced to minimum, and the turbine is tripped. The electromatic valve may be used for venting. This is done by selecting the "Manual" position on the control room selector switch.

During the shutdown process, the main steam and reheat piping startup drains are opened to drain all moisture from the steam lines.

In a normal, controlled shutdown, the steam line drain valves open at about 20 percent turbine generator load. No other operator action is required. On a turbine generator trip the stop valves in the steam leads and the non-return valves in the extraction lines close automatically. Operator attention is required to confirm operation of these valves.

During long periods of shutdown, the HR/SR and main steam piping are blanketed with nitrogen to reduce the formation of corrosion products which can cause increased maintenance problems.

2.5.5.2 Steam Bypass and Startup

The steam bypass and startup system permits 50 percent of full-load steam flow to bypass the main turbine to the main condenser during plant operation. During startup the system allows steam flow to be established quickly through the reheater to facilitate turbine - steam temperature matching. Arrangement and equipment are depicted on Fluid System Diagram 8270-1-504-302-031.

Two stages of bypass are involved. A high pressure bypass conveys steam from the superheater steam header to the cold reheat header, and a low pressure bypass routes steam from the hot reheat header to the main condenser. Desuperheating water for the high pressure bypass stage is taken from the boiler feedwater pump discharge and from the main feedwater pump interstage bleed for the intermediate pressure stage. Both stages of bypass are interlocked so that steam cannot be bypassed if desuperheating spray is unavailable. In addition, bypass to the condenser will be stopped if condenser pressure is too high.

During a cold or warm startup the set-point pressure of the high pressure bypass pressure valves are regulated to match generated steam pressure. With bypass flow established through the reheater, the turbine temperature rate-of-increase is matched to steam temperature rate of increase. This minimizes time to reach turbine synchronization and loading.

2.5.5.3 Extraction Steam

Steam is extracted from four points of the main turbine and used for regenerative feedwater heating. The highest pressure extraction point is at the high pressure turbine exhaust which provides cold reheat steam to feedwater heaters 4A and 4B (see Fluid System Diagram 8270-1-503-302-041 for schematic arrangement of Extraction Steam system equipment). There are two extraction points in the intermediate pressure turbine section; one supplies steam to feedwater heaters 3A and 3B, and the second supplies steam to feedwater heaters 2A and 2B. One extraction from the low pressure turbine supplies steam to the deaerator.

In the event of a turbine trip, the turbine is protected from overspeed by preventing reverse flow of flash steam from the heaters with positive closing, balanced disc, non-return valves located in the extraction lines. The valves are located in horizontal piping runs close to the turbine. To prevent water from entering the turbine stages, motor-operated gate valves are installed in the extraction lines to close automatically if a high water level is sensed in the heaters. These valves are locked in the closed position until the level monitor indicates normal water level.

The steam extraction system is a base load system, designed for operation at 75 to 100 percent of rated load. No special operator action will be required for cycling except opening of drain valves at loads below 25 percent.

2.5.5.4 Condensate

The condensate system conveys the condensed steam from the condenser hotwell through the steam seal exhauster-condenser, steam jet air ejector condensers, demineralizer, and into the deaerating heater. Flow and arrangement are shown on Fluid System Diagram 8270-1-511-302-101.

2.5.5.4.1 Flow Description

Exhaust steam from the low pressure turbine and the boiler feedwater turbines exhausts directly into the main condenser. The two oxidant compressor drives

and the ASU compressor drive each have their own condensers, from which condensate drains to the main condenser hotwell.

Two mechanical vacuum pumps, of 100 percent capacity each, are available to evacuate noncondensable gases to maintain vacuum. The pumps are supplemented by a two-stage, steam jet air ejector.

The system normally uses two of the three condensate pumps, each 50 percent of design capacity. They pump condensate through a gland seal exhauster-condenser, steam jet air ejector condensers, and a demineralizer before going to the deaerator. A recirculation line is routed to the condenser so minimum flow through the steam seal exhauster-condenser can be maintained during low load.

A condensate storage tank is provided to absorb surges and supply condensate as needed. Excess liquid flows to the storage tank through the spillover valve which opens when the hotwell level goes above its high level. Makeup water is admitted to the cycle through a makeup control valve into the condenser. The elevation of the condensate storage tank and the low pressure in the condenser provide sufficient head to meet normal flow requirements. An emergency makeup valve opens if higher flows are needed or when the condenser is not at "vacuum" conditions.

2.5.5.4.2 Major Equipment

Major equipment consists of steam surface condensers, condensate pumps, condensate storage tank, demineralizer, deaerator, and deaerator storage tank. Design information for these components is summarized in Table 2-11.

TABLE 2-11
CONDENSATE SYSTEM EQUIPMENT

1. Demineralizer

The condensate demineralizer polishes condensate and provides startup-cleanup recirculation before passing boiler feedwater to the HR/SR. Two 100 percent deep bed units are available.

2. Deaerator and Storage Tank

| | |
|---|---|
| Type | Horizontal, spray tray |
| Operating Pressure, psia | 15.04 |
| Outlet water flow, lb/hr | 1,070,992 |
| Temperature, $^{o}F$ | 213.2 |
| Storage tank, diameter ft-in. | 10-8 |
| length ft-in. | 25-6 |
| Capacity, gal | 12,000 |

3. Condensers

| | Main Turbine Generator & BFW Pump Turbines | Oxidant Comp. Turbines | ASU Comp. Turbine |
|---|---|---|---|
| Number | 1 | 2 | 1 |
| Surface, sq. ft. | 57,000 | 7,600 | 8,000 |
| Tube material | Copper-nickel | Copper-nickel | Copper-nickel |
| Tube Size, in OD-BWG | 7/8 - 18 | 7/8 - 18 | 7/8 - 18 |
| Tube Length, feet | 25 | 20 | 20 |
| Water, gpm | 51,200 | 8,500 | 8,900 |
| Water Temp. in, °F | 69 | 69 | 69 |
| Water Temp. out, °F | 92 | 92 | 92 |
| Pressure, in. Hg abs. | 2.0 | 2.5 | 2.5 |

4. Condensate Pumps

| | |
|---|---|
| Type | Vertical, centrifugal, multi-stage |
| Number | Three |
| Capacity, gpm | 950 |
| Head, feet | 200 |
| Net Positive Suction Head (NPSH), feet | 10 |
| Brake horsepower | 75 |

2.5.5.4.3 Modes of Operation

1. Startup

The condensate system is one of the first systems to be placed in operation during plant startup. The system supplies cooling water to the steam seal exhauster, sealing water to main feedwater pump seals, boiler fill water and miscellaneous condensate services.

Startup from a "dry" state involves the filling of the condenser hotwell and the HR/SR. The condenser hotwell is filled by opening the fill valve at the main condenser and admitting water from the condensate storage tank. After the hotwell is filled, the condensate pumps are started and the condensate system, from the condenser to the main system shutoff valve and bypass line, is vented and filled. Once flow is established through the bypass line, the feedwater system may be started and the HR/SR filled.

For normal startup, after the HR/SR and condenser hotwell are filled, the next step is to vent and fill the condensate system. The condensate pumps are started with main system shutoffs closed and the control valves open. With the lower flow through the empty system, system fill is accomplished without causing severe water hammer. After the condensate system is filled and vented, the plant cleanup cycle can begin.

During the turbine warmup cycle with the main turbine on turning gear, sealing steam is supplied to the turbine glands, the condenser vacuum pumps are started, the steam sparger in the deaerator is turned on, and the condensate is recirculated until the oxygen content and the pH are within prescribed limits.

The level in the condenser hotwell is maintained by the static height of the stored water in the condensate storage tank. One set of controls governs the amount of makeup or dump required. The discharge from the condensate pumps passes through the steam seal exhauster and a blowdown cooler, and then to the deaerator. The system requires no operator action after startup, except normal surveillance. The system head floats on the system curve, depending on load. The temperature of the condensate from the deaerator is dependent on turbine loading.

2. Normal Operation

The unit, and consequently the condensate system, is normally operated at full load, with a small percentage of part load operation between 75 and 100 percent.

The condensate system is capable of operating satisfactorily and with no special operator action in the event of load changes on the unit.

The standby condensate pump is arranged for automatic start on an electrical trip of a running pump.

3. Shutdown

Equipment may be removed from service by closing isolation valves and opening bypass valves (except the seal steam exhauster-condenser) in accordance with operating instructions provided by the equipment manufacturer.

A high-high water level in the deaerator storage tank or low water level in the main condenser hotwell causes closure of the deaerator inlet isolation valve. A very low condenser hotwell level will cause a trip of the condensate pumps.

Two condensate pumps must be kept in service until the condensate/feedwater flow requirement has fallen below 50 percent of full load, and must remain in operation on recirculation until the gland seal exhauster-condenser is shutdown. The Condensate and Boiler Feedwater Systems must be in operation whenever hot gases are flowing through the Topping cycle.

4. Special or Infrequent Operation

The condensate system valves and controls are designed to prevent water induction and steam reverse flow from entering the main steam turbine following a turbine trip. A high feedwater level in the deaerator diverts incoming drains directly to the main condenser. A high-high level closes the non-return valves and the stop valve and opens the extraction piping drain valves. This effectively removes the deaerator from the system and prevents water induction into the main steam turbine.

During a steam dump to the main condenser, the Condensate System may be affected by a deterioration in vacuum, an increase in condensate temperature, and a fluctuation of level in the condenser hotwell.

### 2.5.5.5 Boiler Feedwater

The boiler feedwater system supplies the fluid that is converted to steam in the HR/SR. Feedwater is used for cooling the MHD Power Train and the flue gas is exhausted from the stack. Flow paths and arrangement are depicted on Fluid System Diagram 8270-1-521-302-081.

#### 2.5.5.5.1 Flow Description

Two booster pumps, each of 100 percent capacity, are available for the feedwater transport from the deaerator storage tank to the suction of the boiler feed pumps. These pumps are located 35 feet below the level of the tank to ensure adequate net positive suction head (NPSH). Discharge from the booster pump is through the channel coolant loop, the low temperature economizer, and to the suction headers of the boiler feedwater pumps.

Boiler feedwater pumps, two 50 percent turbine-driven pumps operating at normal load and a reserve 50 percent variable-speed motor driven pump, transport the feedwater through the feedwater heaters, the high temperature economizer, the MHD power train (except channel), and in to the HR/SR steam drum.

Boiler feedwater purity is monitored continuously and sampled to ensure that required quality is maintained.

#### 2.5.5.5.2 Major Equipment

Flow rates and conditions shown for the major equipment are for base load operation as indicated on System Heat and Mass Balance Drawing No. 8270-1-540-314-001. The equipment includes the booster pumps, feedwater pumps and drives, and feedwater heaters. Design information for these components is summarized in Table 2-12.

TABLE 2-12
BOILER FEEDWATER SYSTEM EQUIPMENT

1. Booster Pumps

| | |
|---|---|
| Quantity | 2 @ 100% |
| Type | Horizontal, centrifugal |
| Capacity, gpm | 2,500 |
| Head, feet | 600 |
| NPSH available, feet | 30 |
| Efficiency, % | 70 |
| Brake horsepower | 517 |
| Motor horsepower | 600 |

2. Main Feedwater Pumps

| | |
|---|---|
| Quantity | 3 @ 50% |
| Type | Horizontal, multistage, centrifugal |
| Capacity, gpm | 1,250 |
| Head, feet | 5,600 |
| Efficiency, % | 75 |
| Brake horsepower | 2,250 |

3. Feedwater Pump Turbine Drives

| | |
|---|---|
| Quantity | 2 |
| Type | Multistage, condensing |
| Power output, hp | 2,300 |
| Steam inlet conditions, °F/psia | 999/395 |
| Exhaust pressure, in. Hg | 2.5 |

4. Feedwater Pump Motor Drive

| | |
|---|---|
| Quantity | 1 |
| Horsepower | 2,300 |
| Speed, rpm | 3,600 |

5. Feedwater Heaters

| | |
|---|---|
| Quantity | 3 stages, 2 half-size per stage |
| Type | Horizontal, 2-pass, U-tube |

2.5.5.5.3 Modes of Operation

1. Startup

The feedwater system startup sequence is as follows:

a. Operational condensate system - condensate pumps on recirculation to condenser - circulating water pumps in operation - condenser vacuum established.

b. System is aligned for normal operation; i.e., necessary valves are in proper position, and system is filled and vented. (With the deaerator at normal level the system may be filled by gravity and vented prior to any pump start.)

c. Auxiliary steam available for sealing turbine, pegging deaerator, etc.

d. Deaerator storage tank level at normal operating point. Deaerator pegged and vented at 2 psig by use of auxiliary steam.

e. Booster pump minimum flow recirculation valves open.

f. A feedwater booster pump is started and cleanup recirculation is established through the booster pump discharge and back to the condenser.

g. Feedwater flow is established through the heater and bypass piping. Flow is alternated as necessary to flush each route. This flush is dumped to the condenser from a point upstream of the high temperature economizer inlet. This flow path is used to clean up and deaerate the water prior to sending the water to the HR/SR. The water is satisfactorily clean for introduction to the radiant boiler when (1) differential pressure has stabilized across a clean suction strainer, and (2) water chemistry has reached satisfactory levels.

h. The motor-driven feedwater pump is started and recirculation is established through the pump recirculation system back to the deaerator. Booster pump cleanup line to the condenser must be closed prior to starting the main pump.

i. The MHD power train is fired at this point using the vitiated air heater to start generation of steam in the HR/SR radiant boiler.

j. When boiler drum conditions reach adequate pressure and temperature, main steam may be used for the turbine shaft seals and to operate a turbine-driven feedwater pump in accordance with the starting requirements of the HR/SR and the main turbine.

k. As the MHD system combustor is fired to increase HR/SR steam temperature and drum metal temperature in accordance with prescribed rates, the steam piping and the main turbine casings are warmed.

l. When unit megawatt load exceeds 40 percent, a second turbine driven main feed pump is brought into service, and pump speeds are paralleled. The motor driven pump may be put on standby whenever the system pumping capacity is satisfied by the turbine driven pumps.

2. Normal Operation

During normal operation of the feedwater system, the system is controlled and monitored from the main control room. Booster pumps and all valve motors are operated from control switches located on the feedwater-condensate panel of the main board.

3. Shutdown

Continuous feedwater delivery is required to maintain boiler drum level and flow through the MHD power train while bringing the plant to a shutdown.

4. Special or Infrequent Operation

A complete loss of feedwater flow to the boiler could occur if power is lost to the feedwater booster pumps. This will cause a plant shutdown. Loss of condensate pumps will result in a forced shutdown unless restored within approximately 5 minutes (deaerator storage tank capacity). On loss of one main feedwater pump, automatic load reduction will commence while the standby motor-driven pump starts to restore flow. Loss of a booster pump will cause automatic reduction of the main feedwater pumps until the standby booster pump can be started and brought up to speed. Low suction pressure will automatically trip the main feedwater pumps.

A feedwater heater string may be removed from service by opening the bypass line and closing the inlet and outlet valves on the heater string to be isolated. Load is reduced in accordance with the turbine manufacturer's instructions.

2.5.5.6 Feedwater Heater Drips

The feedwater heater drips system maintains normal water levels in the feedwater heaters and controls flow of condensate to the deaerator. In performing these services the system functions to prevent liquid water surges to the turbine blading stages. Drip control flow cascades from the higher extraction pressure feedwater heaters to the lower and then to the (low pressure) flash tank. Steam from the flash tank flows to the deaerator. During startup or in the event of high water level the feedwater heaters can drain directly to the main condenser. Arrangement and flow paths are shown on Fluid System Diagram 8270-1-525-302-111.

There are three stages of closed feedwater heaters in two parallel loops of 50 percent capacity. Thus stages 2A, 3A, and 4A are in series and 2B, 3B, and 4B are in series. The first stage of heating is in the deaerator. The heaters cascade normally from full load to 20 percent load. At startup, below 20 percent load, and in an emergency (operational malfunction) each heater has an alternate drain to the main condenser. In the event of turbine trip positively actuated non-return extraction valves close automatically to prevent flashed steam from flowing in reverse through the extraction steam piping and impacting on the turbine blades.

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2.5.5.7 Feedwater Heater and Miscellaneous Drains, Vents and Reliefs

The feedwater heater vents, drains and reliefs system provides draining and venting of the feedwater heaters to the main condenser. Miscellaneous drains convey condensate drains from the following steam lines to the main condenser:

HP Turbine Main Steam (2 lines)
HP Turbine exhaust (2 lines)
Cold Reheat
Extraction Steam to Feedwater Heaters 4A and 4B (2 lines)
Hot Reheat Steam to IP Turbine (2 lines)
Extraction Steam to Feedwater Heaters 3A and 3B
Extraction Steam to Feedwater Heaters 2A and 2B
Intermediate Pressure to Low Pressure Cross Over
Deaeration Extraction Steam
Hot Reheat Steam to Boiler Feed Pump Turbines
Hot Reheat Steam to Oxidant Turbine
Hot Reheat Steam to ASU Turbine

Flows and arrangements are shown on Fluid System Diagrams 8270-1-525-302-113 and 8270-1-519-302-121.

2.5.5.8 Condenser Air Removal

The condenser air removal system removes non-condensable gases from the steam space of the main and oxidant system surface condensers. Gases are removed by means of a steam jet air ejector (SJAE) and rotary vacuum pump systems and discharged to the atmosphere. Flow arrangement is shown on Fluid System Diagram 8270-1-491-302-131.

Each surface condenser has an air removal line in each water box (divided). These lines exhaust to a common header from which separate lines go to the SJAE and two 50 percent capacity vacuum pump systems. During normal operation the SJAE is used for holding vacuum or as a backup to the pumps in the event of air surges. For low absolute pressures (high vacuum) the vacuum pumps operate in series with automatically controlled air ejectors. This air ejector, which employs an air jet, acts as a hogger during startup and to reduce pressure surges due to excess non-condensables in the steam exhausted to the condensers.

For normal operation, one pump system operates while the other is on standby. The standby pump system starts automatically if the set level of pressure increases (vacuum decreases).

The condenser air removal system must be operative before startup of the condensing turbines. Gland steam sealing pressure can be established by the operator through use of the auxiliary boiler steam supply.

2.5.5.9 Circulating Water

The Circulating Water System supplies cooling water for the main and auxiliary condensers and for power plant heat exchangers. Arrangement and flow patterns are shown on Fluid System Diagram 8270-1-571-302-201.

Circulating water, after extracting heat from the plant condensers and heat exchangers, is pumped to the top of the cooling tower. From there it is sprayed over cooling tower trays and it flows downward through the staged trays to the tower basin. Air enters horizontally at the bottom of the tower by induced draft and flows through the falling water. Since cooling is primarily by evaporation, the wet bulb temperature of ambient air is the important parameter.

Cooled water in the basin flows through the flume and screens to the suction of vertical circulating water pumps which discharge water to the plant condensers. Separate service water pumps are provided to pump circulating water through plant heat exchangers.

The cooling towers are mechanical draft, cross-counter flow type arranged in two parallel flow units each with four cells. Each cell is an entity cooling unit with its own structure, tray stages, water pipe headers and top mounted fan. During plant operation in cold weather, a portion of the heated circulating water is bypassed around the cell to prevent icing. Each cell can be isolated for service and full load can be maintained with one cell out of service.

All pumps are vertical mixed-flow type. The pressure developed is primarily a function of the height above the tower basin to the top of the tower for water lift. Flow friction through piping and heat exchangers at maximum flow are other major design criteria for sizing the pumps. Pump discharge valves are interlocked with the pump motors so that pump startup occurs at a predetermined valve opening point. Motor and valve interlocks prevent the pump from being run in reverse. In the anticipated event of large steam dump to the condenser, the operator may place all cooling tower cells in operation to help remove the excess heat load.

### 2.5.6 Plant Auxiliary Systems

#### 2.5.6.1 Auxiliary Steam

The Auxiliary Steam System will provide up to 200,000 pounds per hour of 115 psi, 350°F steam for plant heating and for auxiliary services during startup and plant operation. Utilization areas are:

- Building heating.
- Flue gas sampling.
- Steam coil air preheater.
- Fuel oil burners.
- Turbine gland sealing (startup and standby).
- Main deaerator and storage tank.
- Auxiliary deaerator sparging system.
- Condensate demineralizers.
- Compressor drive turbine warming.
- Steam coil supply.
- Auxiliary boiler deaerator supply.

Arrangement and flows are shown on Fluid System Diagram 8270-1-507-302-501.

The two auxiliary boilers are oil-fired, natural circulation, packaged units with a maximum continuous rating of 100,000 pounds per hour, each.

During startup of the power system, the auxiliary boilers provide steam for air preheating, oil burner atomization, to warm and deaerate the condensate/feedwater, and to provide other auxiliary warming and pegging steam as needed.

#### 2.5.6.2 Boiler Flue Gas System

The Boiler Flue Gas System provides the ducting and components for transporting boiler flue gas from the HR/SR boiler to the ESP and to various bottoming side components, such as the low temperature economizer, the afterburner gas supply air heater, and the coal pulverizing mills. The arrangement of system components (excluding the HR/SR boiler and the ESP) and the connecting ductwork are shown schematically on Fluid System Diagrams 8270-1- 403-302-301, 8270-1-403-302-322, and 8270-1-403-302-323.

The 480°F flue gas from the HR/SR boiler flows into the ESP at the rate of 1.35 millions pounds per hour and 14,649 pounds per hour of ash/seed mixture are removed during 100 percent normal power operation. The cleaned flue gas from the ESP is then split into multiple streams as required for the following subsystem functions:

1. Coal Drying and Transport Gas (Fluid System Diagram 8270-1-403-302-323)

   Flue gas at a rate of 564,000 pounds per hour is conveyed by two 50 percent capacity blowers to the pulverizer mills for coal drying and transport to the coal processing baghouse. The coal fines are removed from the flue gas in the baghouse and the cleaned gas is returned to the

intake of the induced draft fans for discharge to the atmosphere via the stack. After passing through the afterburner gas supply air heater, 5500 pounds per hour of flue gas are directed to the transport gas compressors where the gas is pressurized and used for transporting the coal from the pressurized lock hoppers to the combustion.

2. Afterburner Gas Supply

   The air heater is supplied with 225,000 pounds per hour of 480°F flue gas for heating the 205,000 pounds per hour of secondary combustion air that is directed to the afterburner section of the HR/SR. Flue gas recirculation is established by the addition of 106,000 pounds per hour of 480°F flue gas to the heated secondary combustion air which produces the total flow of 311,000 pounds per hour of afterburner gas supply to the HR/SR. The flue gas exhaust from the air heater is directed to the induced draft fans for discharge to the atmosphere.

3. Low Temperature Economizer

   The remaining 438,000 pounds per hour of flue gas from the ESP flows through the low temperature economizer providing 5.5 $MW_t$ of heat transfer to the boiler feedwater. The flue gas is then exhausted to the induced draft fans.

All of the returned flue gas streams with a combined total flow of 1,259 million pounds per hour are directed to the intake header for the induced draft fan. Two of the three induced draft fans (50 percent capacity each) discharge the cleaned flue gas to the atmosphere via a 300 foot high stack.

2.5.6.3 Coal Management

Coal management consists of the following functions:

Receiving and unloading
Storing
Screening and crushing
Pulverizing and drying
Pressurized storage
Injection to the combustor

2.5.6.3.1 Yard Coal Handling

At full load the ETF will require 101.8 tons of raw coal per hour. However, during the first 24 months of operation, the plant is expected to be in a test phase wherein full load will be maintained for 2,000 hours per year, or a 23 percent capacity factor. During this period, coal requirements will be 206,000 tons per year. Full load commercial operation at a 70 percent capacity factor requires an annual coal supply of 624,000 tons. Using the latter basis, the coal yard storage is sized for a 60 day supply. Drawings No. 8270-1-240-002-001 and 8270-1-240-002-002 show the yard coal handling arrangement.

1. Rail Car Unloading

The coal unloading and storing facility located in the northwest corner of the plant is 800 feet long and 500 feet wide. A thawing process for rail cars is provided for winter handling of coal. As an additional measure, a Freeze Control Agent (FCA) with glycol based compounds may be used to weaken the crystalline structure of ice. The FCA would be sprayed on coal at a cascade point on the coal belt conveyor at the mine or after the coal is loaded in the train.

A rotary dumping rail unloading system is provided. The system requires a minimum of 3-1/2 to 4 hours for thawing and unloading a unit train with 100 cars. Gondola type cars of random size up to 100 ton capacity can be accommodated without adjustment or loss of cycle time using the unit train concept. This is accomplished by the use of cars with rotary couplers and approximately three miles of track around the perimeter of the site.

The 400 feet long (8 car-length) thawing shed equipped with infrared electric heaters is located at the coal unloading facility. The average electrical power consumption for the thawing shed is about 7,000 kW. The thawing shed is divided into 8 zones of 50 feet each. The first four zones from the approach end are utilized as thawing bays equipped with heaters, and the remaining four zones as soaking bays without heaters. Special care is required to avoid stress and damage to the cars due to overheating.

After a car has proceeded through the thaw shed, it enters a hydraulic car positioner unit. Locomotives are used only to spot the train for the initial stop in the thaw shed. After that, all train motion is controlled by the car positioner. The positioner unit consists of two hydraulic rams, one located on each side of the tracks. Each ram has two carriage arms, one for acceleration and one for deceleration.

Once the coal car has been positioned it is ready for weighing and dumping. Scales located before and after the rotary car dumping device record the loaded car weight (gross) and the empty car weight (tare) for each car. Normally, a rotation of 160 degrees is used for dumping; however, 180 degrees maximum rotation can be utilized if required. Each car is furnished with rotary couplers to enable dumping without disengagement. Two electric eyes detect any misaligned cars and will prevent dumping in such an event. As car rotation begins, four hydraulic clamps engage the top of the car. Limit switches monitor the clamping and stop the rotation if secure clamping has not been obtained.

The coal is dumped into a 300 ton-capacity unloading hopper located 60 feet below the dumper. Above the hopper a bar screen with 12 inch openings and runway space for a small tractor-dozer is provided to break up large or frozen chunks of coal to avoid blockage or damage to the downstream coal handling equipment. The hopper is constructed of 1/4 inch thick steel plate with a 1/8 inch thick stainless steel liner. Four outlets, with slide gates, direct the coal into four reciprocating,

plate type, vibrating feeders each rated at 1,000 tons per hour. These feeders discharge onto the short 54 inch wide belt (No. 1 conveyor), which in turn discharges through a chute onto a long 54 inch wide belt conveyor No. 2. Belt conveyor No. 2 is a long belt transporting coal from underground to the sample house and to the transfer tower. Belt conveyors No. 1 and No. 2 are each rated at 1,750 tons per hour, 450 feet per minute.

2. Storage Bunker

At the sample house, the physical and the chemical properties of coal will be tested. The transfer tower is equipped with a mechanical dust collector and coal sampling equipment. The transfer surge bin has two conical discharge chutes with the openings controlled by power actuated slide gates. From these two chutes, the coal can be diverted to two 54 inch wide belt conveyors No. 3A and 3B. These conveyors are rated at 1,750 tons per hour, 450 feet per minute and deliver coal into the top of lowering wells which establish active coal piles. Excess coal is moved to long term storage and packed down by rubber tired dozers and bulldozer scrapers. There is 30 days storage in each of two long term piles. Each coal pile is equipped with a lowering well.

Four vibrating feeders and four hoppers are located below grade in a concrete trench in line with each lowering well. The vibrating feeders dump the coal into 42 inch wide belt conveyors No. 4A and No. 4B rated at 1,000 tons per hour, 450 feet per minute.

Belt conveyors No. 4A and No. 4B pass through weigh scales which monitor the tonnage of coal in transit and transmit the data to the station control room. The station operator (upon advice from the chemist) can vary the feeder rates to obtain the required quality of the coal by blending coals from each of the two piles. Belt conveyors No. 4A and No. 4B feed a 500 ton surge bin located in the control transfer house. The bin feeds two crushers rated at 500 tons per hour and takes the run-of-mine coal down to 1-1/2 inch size or less which is suitable for the pulverizers. From the two crushers, coal is fed by gravity to two 30 inch wide belt conveyors No. 5A and No. 5B, rated at 500 tons per hour, 450 fpm. The control transfer house is also equipped with mechanical dust collecting equipment.

3. Coal Transport System

Belt conveyors No. 5A and No. 5B feed into a 2,000 ton storage capacity bunker at an elevation of 150 feet via the coal tripper. This tripper is rated at 500 tons per hour, and can be fed by either belt conveyor No. 5A or No. 5B. The bunker is suitable for 16 hours of storage and is equipped with a dust suppression system. From the storage bunker, the coal is fed by large diameter pipes into weigh-feeders which measure and distribute the coal to two of the three 55 tons per hour capacity pulverizers. One of the pulverizers acts as a spare. To reduce coal dust problems, a slight negative pressure will be maintained in the coal preparation building by induced draft fans equipped with high efficiency dust collectors.

For coal drying in the pulverizer, approximately 564,000 pounds per hour of flue gas (2.75 pounds of gas per pound of as-received coal) is tapped from the main gas stream between the ESP and the low temperature economizer. In the pulverizer, coal is dried to 5 percent moisture by weight and pulverized to 70 percent-200 mesh size. At design capacity, the ETF plant consumes 83 tons per hour of dried coal. The mixture of pulverized coal and wet flue gas is separated in a baghouse, where the coal is collected and transported to four 150 ton capacity (each) coal lock hoppers. The flue gas is discharged to the stack.

2.5.6.3.2 Coal Feed Lock Hoppers

The dried pulverized coal is transferred through pneumatic valves and feeders to two depressurized 150 ton capacity (each) lock hoppers (A1 and A2), as shown on Fluid System Diagram 8270-1-410-302-341. At the same time, the other two pressurized lock hoppers (B1 and B2) are feeding coal to the continuously pressurized primary injector B. All the slide gate valves are supplied with seal air. All the lock hoppers and primary injectors are pressurized with dry nitrogen at startup and then switched to flue gas (at a minimum pressure of 72 psia). The coal feeding to the primary injector takes place without interrupting the continuous injection of coal from the primary injector to the combustor. The lock hopper and primary injector are stacked. All the lock hoppers and primary injectors have a rupture disc with bag filters on the discharge to release overpressure to the atmosphere. Approximately one pound of high pressure gas transports 30 pounds of coal from the primary injector to the coal feeder header located around the first stage of the combustor. A pressure differential controller balances the air pressure between the primary injector outlet and the coal feed line. The signals from the combustor burner control system regulate the speed of the coal feeder and the flow of the high pressure transport gas to the combustor. Drawing No. 8270-1-410-302-341 shows the coal feed lock hopper arrangement.

2.5.6.4 Seed Management

The Seed Management System receives and unloads fresh seed; recovers spent seed from the HR/SR boiler and ESP; conveys, stores, pulverizes, mixes and injects prescribed fractions of fresh and spent seed into the MHD combustor; and trucks spent seed to an off-site location for either reprocessing or disposal.

2.5.6.4.1 Yard Seed Handling

Drawings 8270-1-240-002-003 and 8270-1-240-002-004 show plan/section views of the fresh seed unloading and storage area. Potassium carbonate ($K_2CO_3$) is delivered to the plant by sealed cars. Approximately 100 tons per day of fresh seed is poured into receiving pits, and moved from there to the 10 day storage silo by screw conveyors.

The seed unloading facility is located on a rail line next to the seed feed building and is provided with an unloading shed to keep the $K_2CO_3$ from picking up moisture.

The spent seed, which is primarily potassium sulfate ($K_2SO_4$), is trucked from the spent seed and fly ash silos to the storage area. The potassium carbonate and recycled potassium sulfate are stored in separate silos which are provided with screw conveyors. Each screw conveyor is designed for 75 tph delivery and 20 tph reclaim rate. The silos are sized for a minimum storage time of 10 days for $K_2CO_3$ and 5 days for $K_2SO_4$ at full load.

2.5.6.4.2 Seed Feed Lock Hoppers

The equipment of the Seed Feed System processes seed from the storage silos for injection into the MHD combustor. This equipment is shown on Drawing 8270-1-410-302-342 and is located in the Seed Feed Building, Building 35, of Drawing 8270-1-210-007-001.

Fresh and recycled seed are reclaimed by screw conveyors from the $K_2CO_3$ and $K_2SO_4$ storage silos and conveyed to the $K_2CO_3$ and $K_2SO_4$ reclaim hoppers. The $K_2CO_3$ and $K_2SO_4$ flows are metered and pulverized separately and mixed at the outlet of the pulverizers.

Between the pulverizers and the combustor, all seed feeding equipment is in duplicate and interconnected for switchover. Seed from the metering bunker to the pulverizers is regulated by the feeders. The pulverizers are specially designed to pulverize seed along with a small fraction of slag, and grind to pass at least 70 percent through a 200 mesh screen. The transport air from the air dryer is used to transport pulverized seed to the cyclone collectors operating at atmospheric pressure.

The cyclone collectors, 50 ton capacity, lock hoppers and primary injectors are stacked vertically. Dry air is provided at the bottom of the lock hoppers and primary injectors to avoid plugging the outlets. High pressure oxidant transports seed from the primary injector to the water cooled seed inlet located near the combustor exit (see Drawing SDD-1101, of SDD- 502). The oxidant leaves the oxidant compressor outlet at a temperature of 433°F.

2.5.6.4.3 Ash/Seed Removal from Power System

Seed is collected from the downstream end of the convective section of the HR/SR boiler and from the ESP. A small fraction of ash is collected with the seed at these locations. No attempt is made to recover the small fraction of seed chemically combined with the Combustor and Radiant Boiler slag.

Hot dry seed is collected from the HR/SR convective section and the ESP via a high temperature hopper/feeder system, and is conveyed to the Spent Seed and Fly Ash Silos (Item 19 of Drawing 8270-1-210-007-001). From these silos, the fraction of spent seed that is to be recycled is shipped by truck to the Seed Unloading Facility (Item 37 of Drawing 8270-1-210-007-001). The remaining fraction is trucked off-site for either reprocessing or sale. Equipment for spent seed collection is shown on Drawing 8270-1-451-302-352.

2.5.6.4.4 Seed Recycle

Spent seed contaminated with fly ash is collected continuously in the HR/SR boiler convective pass and ESP hoppers. The spent seed exit temperature from the ESP hoppers is about 480°F. The maximum flow rate of the spent seed mixture of 27,889 lb/hr with 11,068 lb/hr being shipped off-site for either sale or reprocessing and 16,821 lb/hr being recycled.

The spent seed mixture is conveyed in a sequential pattern from these hoppers through one of the two air lock feeders into a positive pressure conveying air stream to the spent seed silos. The fraction of spent seed that is to be recycled is shipped by truck from the spent seed silos to the Seed Unloading Facility (Item 37 of Drawing 8270-1-210-007-001).

2.5.6.5 Slag Management

Slag management consists of collecting, grinding, separating, transporting and eventual disposal of the slag residue of the fuel.

For coal containing the design maximum ash content, 12-1/2 tons of slag per hour will enter the system. At the combustor, the slag handling equipment is designed for 10 tons of slag per hour. Radiant boiler slag handling equipment is designed for 2- 1/2 tons per hour. Arrangement of equipment is shown on Fluid System Diagram 8270-1-451-302-351.

The pressurized slag rejection equipment at the combustor is part of the MHD Power Train System design. Slag is collected in pressure cascaded collection tanks and then crushed. Two sluice pumps use water to transport the bulk of the crushed slag to one of two dewatering bins. Slag that has settled and been dewatered is trucked to off-site disposal. Alternately, the water/slag slurry may be bypassed around the dewatering bins and routed to the slag disposal pond. Clear water is reclaimed and pumped from the bins to the recirculating and settling tank, from which it is recirculated into the system.

Slag collection tanks at the radiant boiler, which are part of the HR/SR system, are not pressurized. Removal from these collection tanks and crushers is by the same method described above for the slag collected in the combustor slag tanks.

The Slag Disposal Pond occupies an area of approximately 108,000 sq. ft. and is shown on the Plot Plan, Drawing No. 8270-1-210-007-001.

2.5.6.6 Electrical

The plant electrical system will:

Deliver power from the MHD power train and turbine generator (T-G) to the 138 kV substation and utility grid.

Distribute power the the 138 kV substation through the bus system to auxiliary systems.

Supply emergency power for plant critical loads.

Provide an uninterruptible power supply for essential circuits.

Accept off-site power during startup, shutdown or facility electrical-fault periods.

The facility power requirements are supplied by the steam turbine driven 160 MVA, 128 MW, 0.8 power factor synchronous generator. This turbine generator is capable of accepting load at 3 MW per minute over its full range and drop from full load to 3 percent load as a step without tripping the turbine.

Four 900 kW combustion turbine-generators provide power on a critical 4.16 kV bus in the event of loss of main power.

Main plant load centers are:

2.5.6.6.1 Switchyard - 138 kV

The switchyard has six 138 kV lines connected through a ring bus. Two lines are used for facility (ETF) output. Two lines are used for facility (ETF) internal power. Two lines connect the facility (ETF) to other utility substations. Extending out from the ring bus, the main plant load centers are:

Inverter bus step-up transformer
Turbine-generator and T-G step-up transformer
Oxidant compressor motor and transformer
MHD station service transformer
Turbine-generator station service transformer

2.5.6.6.2 Inverter Bus Step-up Transformer

The transformer delivers power from the MHD power train to the switchyard. Power is synchronized with the 138 kV system.

2.5.6.6.3 Turbine-Generator and T-G Step-up Transformer

The turbine-generator produces electrical power from the bottoming plant and delivers it to the switchyard, synchronous with the 138 kV system via the T-G step-up transformer. Three of the six generator winding leads are connected to the step-up transformer isolated phase bus. The three neutral leads are connected to ground via the primary winding of a 15,000 to 240 V single-phase distribution transformer. A resistor across the 240 V secondary limits ground current to low amperage.

2.5.6.6.4 Oxidant Compressor Transformer and Motor

An overhead line from a 138 kV switchyard supply services the oxidant compressor transformer. When not in service for the compressor motor, this transformer serves as a backup for the MHD station service transformer.

2.5.6.6.5 MHD and T-G Station Service Transformers

The primary windings of the MHD and station service transformers are supplied through two 138 kV overhead lines originating at respective switches on the 138 kV ring bus.

2.5.6.6.6 Main MHD and T-G 4.16 kV Metal Clad Switchgear

The switchgear has independent busses, one for MHD loads, one for T-G loads. Auxiliary power for the plant is provided through 10 feeder breakers off the switchgear busses. Either circuit, MHD or T-G can supply full power requirements, and the busses have a tie-line for interchangeability.

2.5.6.6.7 Critical Metal Clad Switchgear

Critical loads obtain power at 4.16 kV and 480 kV from the critical switchgear. If normal power is lost, the emergency combustion turbine generators start automatically and supply power to the critical bus.

2.5.6.6.8 Medium Voltage 4.16 kV Starters

Four bus line-ups of starters are available for motors 250 hp and larger. These busses are tied to the MHD switchgear bus A, bus B and two breakers on critical bus C respectively.

2.5.6.6.9 480 V Load Center

A transformer tied to bus A and another tied to bus B provide power for motors 200 hp and smaller. Bus-transformer sets are redundant and a tie breaker allows either transformer to operate off either bus.

2.5.6.6.10 480 V Cooling Tower Load Center

The cooling tower 480 V load center takes power from a breaker on the 4.16 kV switchgear.

2.5.6.6.11 Coal Management Load Center and 4.16 kV Starter

Power is supplied to the coal management load center from a breaker on the 4.16 kV switchgear. A 4.16 kV full voltage non-reversing starter takes power from the 4.16 kV primary cable supplying the 480 V load center transformer.

2.5.6.6.12 Thaw Shed 480 V Load Centers (4)

Thaw shed load centers 1 and 2, receive power from breaker 5B, and centers 3 and 4 receive power from breaker 6, both on the 4.16 kV switchgear. Each load center has 5 feeder breakers supplying 350 kW power respectively for the infrared heating load. This large block of power is required for thawing of coal trains during cold weather.

2.5.6.6.13 Critical 480 V Load Center

Critical bus 4.16 kV switchgear breaker 4C supplies power to the critical load center transformer. This power is essential for orderly plant shutdown during interruptions of normal power.

2.5.6.6.14 Uninterruptible Power Supply (UPS) Systems

Two UPS systems are provided. One supplies power to the inverter computer control and electrical controls. The other supplies power to vital instrumentation. Each UPS system has a 60 cell, 125 V dc battery and redundant battery chargers and inverters.

2.5.6.6.15 Plant dc Systems

A 125 V dc 60 cell lead calcium battery provides power for plant dc requirements.

## 2.5.7 Plant Services

### 2.5.7.1 Closed Cycle Cooling Water System (CCCWS)

The CCCWS circulates cooled, treated demineralized water through a closed piping system to equipment in the turbine generator, compressor, HR/SR and MHD buildings. Flow rates, pressures, and temperatures are shown on Fluid System Diagrams 8270-1-531-302-231 and 8270-1-531-302-232.

An elevated CCCWS atmospheric head tank is provided to maintain a reserve volume of treated water and to maintain a positive pressure on the CCCWS pumps. A chemical treatment tank is connected across the CCCWS pump discharge and suction piping to maintain required water properties. The closed cycle cooling water is pumped through station heat exchangers and is cooled by raw service water from the Circulating Water System. The cooled closed cycle cooling water flows from the heat exchanger to all auxiliary coolers and returns to the CCCWS pump suction manifold. Makeup is taken from the main condensate system.

Main equipment serviced by the CCCWS includes:

- Generator hydrogen coolers
- Main turbine lube oil coolers
- ASU turbine lube oil coolers
- Oxidant compressor turbine lube oil coolers
- Main boiler feed pump turbine lube oil coolers
- MHD magnet accessories
- Coal pulverizer mills
- Plant service/instrument air compressor inter- and after-coolers
- Bearing cooling for induced draft fans, condensate pumps, boiler feed pumps and boiler feedwater booster pumps
- Magnet warm bore liner

### 2.5.7.2 Plant Makeup Water

The Plant Makeup Water system stores, transfers and conditions plant water sources. These sources provide makeup for:

- Cooling towers
- Primary cycle water
- Potable usage
- Fire service
- Plant services such as cleaning, filling, flushing, and washing.

Makeup water may be obtained from a combination of wells and nearby streams or lakes. The major makeup, some 4,000 gpm, will be for the cooling tower; this makeup should come from local surface sources. Potable water is expected to be well water.

Major equipment are the storage tanks, a 400,000 gallon supply for filtered water and fire water backup, and a 300,000 gallon supply of raw water, which with proper treatment can be used for any plant purpose. Arrangement and servicing equipment are shown on Fluid System Diagram 8270-1-582-302-161.

### 2.5.7.3 Sampling

The sampling system collects and conditions water and steam samples to obtain chemical analyses and continuously records the chemical characteristics of the samples. This sampling system provides data to ensure that established chemical limitations for operation are maintained. Sampling flow arrangements are shown on Fluid System Diagram 8270-1-633-302-181. Operating temperatures and pressure at selected points are as follows:

TABLE 2-13
SAMPLING POINTS

| Point | Source | Temperature °F | Pressure, psig |
|---|---|---|---|
| AE-1 | Condenser hotwell | 101 | 1.5 (in. Hg abs.) to 100 (psig) |
| AE-2 | Condensate pump discharge | 101 | 100 |
| AE-3 | Condensate demin. outlet | 101 | 50 |
| AE-4A, 4B | H.P. heater drains | 369 | 155 |
| AE-5 | BFW booster pump discharge | 215 | 235 |
| AE-6 | BFW pump suction | 303 | 200 |
| AE-7 | H.T. economizer inlet | 450 | 2,270 |
| AE-8 | Combustor FW inlet | 530 | 2,270 |
| AE-9 | Radiant boiler inlet | 637 | 2,270 |
| AE-10 | Drum steam | 637 | 2,000 |
| AE-11 | Boiler blowdown | 637 | 2,000 |
| AE-12 | Main steam | 1,005 | 1,900 |
| AE-13 | Cold reheat steam | 650 | 435 |
| AE-14 | Hot reheat steam | 1,005 | 415 |

Condensate, feedwater, heater drains, steam and blowdown samples are conveyed through stainless steel tubing to a Primary Cooler Rack. Samples are cooled to 115°F ± 5 and, if above 200 psig, are throttled to reduce pressure. Samples are then cooled at a second rack to the 77°F sampling temperature.

Samples are sent (after cooling) to the recorder analyzer panel for continuous analysis and recording for AE-1, AE-2, AE-3, AE-5, AE-7, AE-10, AE-11, and AE-12.

Samples, after analysis, drain to the plant drain system.

### 2.5.7.4 Industrial Gas Systems

The Industrial Gas System consists of the Plant Service and Instrument Air Supply System as shown on Fluid System Diagram 8270-1-652-302-241 and Miscellaneous Gases as shown on Fluid System Diagram 8270-1-652-302-242.

#### 2.5.7.4.1 Plant Service Air and Instrument Air Supply System

Reciprocating air compressors deliver a minimum of 1,000 scfm clean, dry, oil-free, -44oF dewpoint compressed air through a single header system throughout the plant for use as either service air or instrument air. A large air receiver located in proximity of the compressors avoids short cycling of the operating compressor and minimizes air surges on the dryers. Smaller air receivers are located throughout the plant to accommodate local high use rates. Two air receivers located in the turbine hall and near the MHD power train are designated as instrument air receivers to provide storage of instrument air for these critical areas.

#### 2.5.7.4.2 Miscellaneous Gases

The Miscellaneous Gases System is a group of four separate subsystems designed to supply industrial type gases for the steam turbine generator, backup supply for the MHD magnet system, and inert gas for blanketing various pieces of equipment throughout the plant. The system consists of the following gases:

1. Helium - provided in bottles for backup to the regular helium distribution system.

2. Carbon dioxide - provided in bottles to purge the hydrogen from the ac generator when it is shut down during outage or for maintenance.

3. Hydrogen - provided in bottles to make up for leakage from the ac generator cooling system, and as a batch supply to refill the system after the generator has been purged.

4. Nitrogen - gaseous nitrogen is received from the air separation unit and is compressed, cooled and stored in tanks. The nitrogen gas is used for blanketing to eliminate potentially explosive conditions in the coal preparation and injection system. Nitrogen and is also used to replace water in steel vessels and piping to reduce possibility of oxygen corrosion when the equipment is out of service.

### 2.5.7.5 Fuel Oil System

The fuel oil storage system is used for startup, shutdown, hot stand-by, station heating and emergency power generation, and is shown on Fluid System Diagram 8270-1-413-302-281.

No. 2 fuel oil is unloaded from rail tank cars into a main oil storage tank; truck unloading is a backup. The main fuel oil storage tank is an above ground tank, diked, vented and designed to provide a one month supply (840,000 gallons) at plant maximum operating fuel oil consumption rates. Fuel

oil transfer pumps provide fuel to four underground fuel oil transfer tanks. Each underground storage tank is fitted with external fill connections, vents, level indicators and electric submersible fuel oil pumps that supply fuel oil to the user and recirculation back to the transfer tank. The four transfer tanks and users are:

Heating boiler for coal system control building
Heating boiler for warehouse
Auxiliary boilers/emergency gas turbine generator/diesel fire pump.
Vitiated air preheater

2.5.7.6 Plant Industrial Waste

The Plant Industrial Waste System collects, stores, transfers and processes as needed the liquid and sanitary wastes generated in the facility so that resulting effluents are in compliance with discharge regulations. The Industrial Waste System is shown on Fluid System Diagram 8270-1-641-302-371.

Major sources of industrial waste are:

Coal pile runoff.
Chimney wash and air heater wash.
Building drains.
Wastewater treatment.
Fuel oil unloading and storage runoff.
Plant yard drainage.
Sanitary wastes.

2.5.7.6.1 Coal Pile Runoff (CPR)

Diking and trenching are provided around the coal storage piles to prevent surface runoff from entering the piles and to collect runoff from the piles for treatment. Runoff goes to a lined collection basin designed for a 10 year, 24 hour per day rainfall. (Rainfall in excess of the design flow may overflow the sump directly to the storm sewer). Large coal particles which settle in the basin are removed periodically and returned to the coal pile.

2.5.7.6.2 Chimney Wash and Air Heater Wash

Chimney and air heater wash are acidic and contain fine ash particles. Wash water flows to the coal pile runoff basin and is fed at a controlled rate through the CPR treatment system.

2.5.7.6.3 Demineralizer Regenerative Waste

The acid and alkaline wastes from makeup and condensate demineralizer regeneration are sent to the batch demineralizer equalization/neutralization tanks. Combined wastes are agitated and checked for pH. Sulfuric acid or caustic solutions are added as needed to "rough" neutralize the wastes. Neutralized wastes are conveyed to the waste collection and equalization tanks with other in-plant wastes for additional processing.

2.5.7.6.4 Building Drains

Water from the coal thaw shed and control building drains and water from the dust suppression system drains to sumps from which it is pumped to the CPR basin. Wastewater collected from floor drains at other buildings, where there is no potential for oil contamination, is pumped to the waste collection and equalization tank. Where oil contamination is probable, sumps are baffled to intercept the oil which is skimmed off manually. The oil is pumped to the oil/water separator in the waste treatment building. Oil is removed to the waste oil holding tank for reclaiming; wastewater goes to the waste collection and equalization tank.

2.5.7.6.5 Wastewater Treatment

The following wastes are directed to the waste collection and equalization tank:

Water pretreatment and treatment wastes such as sludge and filter backwash.

Fly ash loading wastes and runoff such as excess water for dust control or spills under the silos.

Slag handling wastes overflow and runoff.

2.5.7.6.6 Fuel Oil Unloading and Storage Area Runoff

The fuel oil unloading areas contain track collector pans, drainage pipes, and curbs for truck loading. Runoff is pumped to an oil/water separator. Skimmed oil from the separator is pumped to an oil reclaim tank.

2.5.7.6.7 Plant Yard Drainage

Rainfall flows through the storm sewer system to the plant yard runoff basin. Drainage will be continuously monitored to prevent accidental discharge of spilled contaminants. Oil day tanks and transformers are diked or set above concrete pits so that spills of oil can be contained. Any rainfall contaminated with oil will be processed through the oil/water separator.

2.5.7.6.8 Sanitary Wastes

Sanitary waste is shown on Fluid System Diagram 8270-1-644-302-381. Sanitary wastes from the ETF are conveyed to an aerated surge tank and from there metered to a sewage treatment plant. Use of the surge tank allows more regulated flow and a more uniform biological loading. After disinfection and sand filtration, the treated effluent will meet local and Federal standards for biochemical oxygen demand, suspended solids and fecal coliform. Waste activated sludge is collected in an aerated sludge holding tank and removed by commercial scavenger service.

The sewage treatment plant is sized to treat an average flow of 8,000 gallons per day, based on a working and transient population of 130 people. Capacity

includes capability for peaks of 105 operating personnel and 250 transient or construction personnel at 50 gallons per day per operator, and 7 gallons per day per construction worker or visitor.

2.5.7.7 Fire Service Water

The fire service water system provides the means to detect and combat fires throughout the facility. Fluids and materials other than water involved in plant fire protection are included generically in this system. The system is shown on Fluid System Diagram 8270-1-781-902-401.

Water for fire protection is stored in the lower portion of the filtered water tank. Supply is adequate for 2 hours (300,000 gallons) and there are no non-fire service connections below this tank volume. A separate 300,000 gallon storage tank is available as a reserve. A separate motor driven fire pump is assigned for fire service and a diesel driven fire pump is in reserve. Both are 100 percent capacity and start automatically when preprogrammed data indicate a need for them. System water pressure is maintained at 125 psig by a separate jockey pump. Isolation valves are located in the fire water loops to localize service loss in the event of pipe rupture or equipment outage. Fixed fire suppression equipment includes:

Wet pipe sprinklers
Dry pipe sprinkler
Automatic water spray
Halon suppression
Preaction sprinklers
Fixed subsurface foam

Nitrogen inerting is provided for:

Coal bunkers
Coal silos
Coal feed lock hoppers

Portable fire extinguishers are to be available throughout the facility and selected to combat specific fire hazards.

Fire detection equipment is to be located in the following structures:

Inverter Building
Compressor Building
Switchgear Building

Manual fire alarms are located throughout the plant. They initiate local warning and remote signals in the main control room.

2.5.7.8 Domestic Services

2.5.7.8.1 Potable Water

Water for drinking, washing or laundering is drawn from the potable water tank. Tank capacity is 4,000 gallons, and is provided with a 120 gpm makeup capacity. See Section 2.5.7.2 for description of Plant Makeup Water System.

2.5.7.9 Heating, Ventilating and Air Conditioning

Heating, ventilating and air conditioning services provide:

Protection against freezing of water supplies
Elimination of unwanted surface condensation
Comfortable working environments
Dilution of extraneous odors
Controlled environments for instrumentation

Major components utilized include:

Water chillers
Steam and electric heaters
Packaged oil fired boilers
Perimeter hot water baseboard heaters

Crossover steam (from exhaust of intermediate pressure turbine to inlet of low pressure turbine) backed by auxiliary steam will be used for steam and hot water heating throughout the plant. Supplementary oil-fired boilers will be available at out buildings such as the coal system control building and the warehouse. Areas needing special conditioning such as the computer room, electrical areas, instrument rooms and control rooms will be provided with duct reheat coils for temperature and humidity control.

TABLE 2-14
MAJOR VENTILATING AND AIR CONDITIONING ZONES

| Zone | Heat Load Btu/hr($10^6$) | Cooling Load Tons | Ventilation CFM($10^3$) | Power HP | Temp Limits °F |
|---|---|---|---|---|---|
| Administration Building | 2,600 | 90 | - | 50 | 78 |
| Compressor Building | 6,050 | - | 272 | 130 | 60 to 104 |
| MHD Building | 4,870 | - | 269 | 260 | 60 to 104 |
| Inverter Building | 1,653 | 401 | 117 | 100 | 60 to 104 |
| Consolidation Area | 825 | 200 | 60 | 50 | 60 to 104 |

## 2.5.8 Facilities

### 2.5.8.1 Yard Coal Handling

When in full operation the ETF will utilize 101.8 tons per hour of as-received Montana Rosebud sub-bituminous coal. Yard facilities include:

1. Rail Car Unloading

   The coal unloading and storage area is 800 feet long and 500 feet wide. Some 3 miles of track around the site provides flexibility for routing and storing cars. Thawing in the 400 foot long sheds consumes power at 7 MW per unit train. Coal is dumped into 300 ton capacity hoppers and conveyed to the coal transfer house.

2. Storage Bunkers

   Excess or initial storage coal is moved to two 30 day storage piles, each 200 feet by 500 feet by 40 feet high. To prevent spontaneous combustion in the pile, the coal should be compacted every 12" to a density of 70 lbs/ft$^3$ ventilated with perforated ducts, and the temperature in the pile monitored.

   Coal being prepared for injection into the combustor is conveyed to storage bunkers which feed the pulverizing mills.

Section 2.5.6.3 describes the coal management equipment and subsystems.

### 2.5.8.2 Yard Seed Handling

Fresh potassium carbonate seed will arrive by sealed railroad car and be unloaded into the hopper shed. From the shed the seed will be conveyed to two 50 foot diameter by 50 feet high silos, each. From the silo the seed moves to the metering hopper and is sent to the pulverizer at a controlled rate.

Recycle seed (potassium sulfate) recovered from the HR/SR is conveyed to storage hoppers and transferred to the spent seed silo. Seed from the silo is trucked to the seed storage area, from which reclaimed measured quantities are admitted to the pulverizer along with fresh seed.

Details of the seed management equipment and subsystems are given in Section 2.5.6.4.

### 2.5.8.3 MHD Building

The MHD area contains the major power equipment of the topping cycle; combustor, generator system, magnet and the supporting systems of cryogenics, consolidation circuitry and the magnet power supply. Total area is 196 feet in the lateral (E-W) direction and 168 feet in the direction of gas flow. The power train is located centrally in an area 76 feet by 110 feet. Bay elevation is 100 feet and the 150 ton capacity crane has a lateral span of 138 feet.

Stray fields from the magnet impose limitations on location of susceptible equipment and access for personnel. See SDD-503, Section 5.5 for limits. Within restricted areas personnel working time is limited as defined in Section 3.11 of the DRD.

The magnet assembly is designed to permit uncoupling from the power train and movement on rails 34 feet (west) during non-operation of the MHD power train. This movement, to a prepared area, will facilitate removal of the channel for maintenance or replacement.

Slag removal tanks are in a 41 foot deep pit beneath the combustor. Pit plan dimensions are 42 feet (E-W) by 18 feet. During MHD Power Train operation voltage potentials at the combustor reach 30,000 V and the collection tanks and the feed lines to the combustor are electrically isolated. During operation access to the power train area will be restricted.

2.5.8.4 Turbine Generator Building

The turbine generator complex, 6 bays wide, (E-W) 168 feet and 3 bays long, 84 feet, houses the main turbine generator, main condenser, boiler feed pumps and drives, feedwater heaters, and auxiliary equipment. Height of the bays is 92 feet. A 100 ton crane on an 84 foot span traverses the area.

A condensate pump pit extends 4 feet below ground level. Ample access area and lay down area is provided, and if necessary heavy pieces can be loaded on flat cars at the railroad bay at the building west end and taken outside for temporary storage or service.

2.5.8.5 Administration and Service Building

This building is a two-story structure containing personnel facilities such as the dispensary, cafeteria, lockers, and lavatories. The main machine shop (serviced by a 20 ton crane), instrumentation and electrical repair shops, and the chemical laboratories are located in this building.

2.5.8.6 Control Complex

The control complex occupies bays extended from the turbine-generator building. From this area operators communicate with, monitor, and regulate all plant operations and functions. During malfunctions or emergencies, the main control room serves as a shelter from which personnel can assess conditions and act accordingly.

2.5.8.7 Cooling Towers

The cooling tower complex is a mechanical draft tower with 4 cells in each of two parallel rectangular units. Plumes and fallout or icing on adjacent areas will be minimal. The cooling tower and pump house occupy an area 140 by 145 feet.

## 2.5.8.8 Miscellaneous Buildings and Structures

1. Heat Recovery/Seed Recovery

   The HR/SR structure covers 5 bays, 140 feet (E-W) by 4 bays, 100 feet and has 8 elevations for a height of 152.5 feet. Four platforms are incorporated for access to soot blowers. The slag pit below the radiant boiler is 11 feet deep.

   The ESP equipment has its own enclosure and is located adjacent to the west end of the HR/SR structure.

2. Air and Oxidant Compressor Building

   The compressor installation, adjacent to the west end of the T-G building is 5 bays longs, 140 feet, by 3 bays wide, 84 feet. Each of the three oxidant compressors each have concrete blast walls around them. A 40 ton crane spans the entire length. The design provides individual condensers placed beneath the two turbine drives of the oxidant compressors and the turbine drive for the Air Separation Unit air compressor. Total building height is 85 feet.

   The Air Separation Unit equipment is located on a concrete base, 84 feet by 84 feet, contiguous to the compressor building. The aftercooler, column and adsorption boxes and the reverse exchanger box are the major installations. The column box is 91.5 feet high.

3. Inverter Building

   The inverter building is adjacent to the MHD building with an area 168 feet wide and 112 feet long. A cooling load of 1 MW is anticipated during operation. Four bays at the east end house the switchgear apparatus. The HVAC unit is located in a penthouse at the north end.

4. Fuel Oil Tank, Dike and Pump House

   Fuel oil storage and pumping facilities occupy a 130 feet by 130 feet area located in the north central area of the site. This installation is designed in accordance with governmental and industry standards.

5. Main Guard House

   The main guard house is located at the main plant entrance and is sized to accommodate the expected personnel influx to the ETF.

6. Substation (Switchyard and Auxiliaries)

   Substation facilities and the filtering and regulating equipment occupy an area 300 feet by 300 feet.

7. Collection and Runoff Ponds

Major pond areas on site include the slag disposal pond in the S-W quadrant, 210 by 420 feet; coal pile runoff basin, south of the coal pile, that collects drains from the pile gutters, 50 by 180 feet; and a storm water runoff basin, 80 by 190 feet.

## 2.6 PLANT OPERATING MODES

### 2.6.1 Startup

The process of initial startup of a new power plant requires a procedure that may extend over months. This follows a checkout phase which may take over a year. The initial startup establishes that all components and system are functioning as specified and that warranties are being met. After the initial startup phase, subsequent operational startup phases occur on planned or impromptu schedules and include cold, warm or hot startup. While the three categories of startup are not firmly defined for the MHD side, they are defined for the steam side. The basis of definition for the different categories of startup is the turbine nozzle chamber temperature, i.e.:

Cold startup; less than 300°F
Warm startup; 300°F to 700°F
Hot startup; over 700°F

The following section describes each of these startup procedures.

#### 2.6.1.1 Initial

Initial startup concurrent with the commissioning of a plant and its being brought on stream is the culmination of many months of established checkout and subsystem preparation. Included in the checkout are:

1. Mechanical Checks:

   a. Hydrostatic testing of piping and pressure vessels.

   b. Flushing and cleaning of flow paths, installation of temporary screens and strainers, final flushing.

   c. Inspection and mechanical checks of:

      (1) Piping and vessels
      (2) Valves
      (3) Pressure relief devices
      (4) HVAC fans
      (5) Pumps

2. Electrical Checks:

   a. Transformers
   b. Control circuits
   c. Switchgear and busses
   d. Power and control cables
   e. Motor control centers
   f. Switchboards, control stations, distribution panels
   g. Motors
   h. Heating elements

3. Instrumentation and Control Checks:

   a. Individual instruments and controls

      (1) Test records
      (2) Installation
      (3) Cleanliness and absence of defects

   b. Static instrument and control circuits:

      (1) Response
      (2) Set point performance
      (3) Accuracy
      (4) Polarity

Major subsystem preparations prior to initial startup include:

Steam line blowdown
Water line flushing and cleanup
Verification of battery and standby power
Availability of plant water supplies
Activation of makeup demineralizers
Condensate cleanup
Feedwater cleanup
Turbine roll
Boiler boil out
Magnet cool down (about one month)
ASU cool down and dryout (3 days)
Verification of coal and seed transport and injection
Low load runs

The limiting item in the prestartup sequence is the one month or longer to bring the magnet to its operating temperature of -451.5°F. Upon completion of the checkout and preparation effort the initial startup becomes consistent with cold startup conditions.

2.6.1.2 Operational

1. Cold Startup

For conventional coal fired power plants the elapsed time from combustor (furnace) shutdown to a "cold" plant is about one week. In that time the temperature of the boiler, turbine, fuel systems, steam lines and water systems will have reduced to ambient. However, it is assumed that cold water circulation and treatment have continued, that oxidant plant cooldown and moisture removal have been accomplished and that the magnet has been maintained at operational temperatures (-451.5°F). (If not, cold startup will occur when those conditions have been attained.)

Major sequencing for the operational cold startup will be (generically) as follows:

a. Cold Water Treatment and Cleanup

Water is recirculated through the primary water loop, bypassing the pendant type steam superheaters, which are not drainable, and the feedwater heaters. At the demineralizer entrance, water samples are taken to determine when cold cleanup is completed. During the cold water cleanup phase, auxiliary steam is used for deaerating and warming the deaerator. This phase will take 3 hours.

b. Purge of Gas Side

The gas side is purged with air to clear away foreign matter, soot or carbon residues. The purge duration is determined by gas sampling and lasts approximately ten minutes. The purge can be performed in parallel with cold water cleanup.

c. Vitiator Firing and Gas Heating

The vitiator is designed to provide 15 percent of rated thermal input or about 80 MW. Excess air to the vitiator and adequate recycle of exhaust gas and air to the HR/SR afterburner will maintain gas temperatures below 1,000°F upstream of the superheater. This temperature limit will be maintained until steam generation and flow has been attained to prevent thermal damage to steam heater tubes. When steam flow is established thermal input will be increased and combustor gas temperatures increased to 2,000°F - $\pm$ 200°F. This phase will take 6 hours.

d. Hot Water Cleanup

Water temperatures will be increased by gas heating and by use of auxiliary steam through the deaerator and deaerator storage tank.

Temperature of the water will be maintained below 550°F until samples indicate that water quality specifications are being met. This phase will take 2 hours.

e. Roll and Synchronize Turbine Generator

Thermal input from the vitiator will increase and steam generated will bring up turbine temperatures. Steam bypass to the reheater and use of auxiliary steam for gland sealing will aid in warmup of turbine components. When turbine temperatures and steam conditions are matched, turbine roll (off the turning gear) will commence. Turbine will be brought to synchronous speed at a programmed rate.

The generator is synchronized by bringing it on line at the exact match of turbine speed corresponding to system frequency. Generator voltage is exactly matched to system voltage in phase and level. This sequence will take 3-1/2 hours.

f. Phase in Main Combustor

After synchronization, the turbine will be brought quickly to 10 percent load. At this point, with combustor temperatures at 2000°F, coal firing to the main combustor will proceed. During the transition of vitiator phase out, major activities will include:

(1) Startup and ramp up of ASU compressor.

(2) Startup and ramp up of turbine drive oxidant compressors (Electric motor drive is used until replaced by turbine drive.)

(3) Activate ESP.

(4) Activate coal processing system upstream of pressurized lock hopper.

(5) Activate Slag Management System.

(6) Establish oxidant and coal flow and regulate until 25 percent of full load mass flow.

(7) Stop vitiator firing.

This sequence will take one hour; the first half-hour is in parallel with generator synchronization.

g. Establish Seed Flow and Conductivity

The following sequences are performed:

(1) Seed injection is initiated and adjusted to a level commensurate with coal mass flow.

(2) Plasma conductivity is verified.

h. Load MHD Generator

At stable thermal input the following operations are performed:

(1) Inverter is activated.

(2) Automatic control is initiated.

(3) Magnet is energized and allowed to ramp upwards.

(4) Oxidant oxygen content is increased to 30 percent as generator loading progresses.

Loading of the generator will continue under automatic programmed control:

(1) Coordinated increase of oxidant, seed and coal flow rates at 1-1/2 percent per minute (corresponding to 2 MW per minute increase at turbine generator).
(2) Verification of state points at predetermined load levels.
(3) Transfer to turbine drives and discontinuance of motor drives as applicable.

i. Stabilize at Base Load

(1) Stabilize at the base load level to attain predetermined optimal conditions.

Loading of generator up to base load will take 2-1/2 hours. Total time for cold startup is ten hours. Major activities and times are summarized on Figure 2-7. Temperature profiles of gas and water/steam during cold startup are shown on Figure 2-8.

2. Warm and Hot Startup

A firm definition of warm startup or hot startup as it applies to the MHD system has not been developed. However, for the purposes of the ETF conceptual design, it is assumed warm startup would not require cold water treatment and cleanup and would take slightly more than 7 hours. Hot startup would eliminate the need for cold and hot water cleanup and to establish steam flow , thereby reducing startup time to approximately 5 hours.

### 2.6.2 Baseload

The ETF is conceived as a baseload plant with a rating of 200 MWe. At full load 87 MWe will be generated in the MHD generator and 128 MWe in the turbine generator. State conditions and flow parameters for this design point are presented on the System Heat and Mass Balance, Drawing No. 8270-1-540-314-001.

As a baseload plant, continuous operation is expected for prolonged periods at loads between 75 and 100 percent of rated capacity. Channel stability requires maintaining channel operation as close to full load as practicable, with subsequent high turndown of the steam bottoming cycle. Thus, a split of 85 percent of full channel power and 60 percent of full turbine generator power is possible, but such turndown ratios are subject to further study. Channel conditions at 75 percent full load flow have been evaluated and a comparison with a coordinated full flow run is presented in Table 2-15.*

*Parameters for the comparative full flow run may differ slightly from current reference conditions.

SEQUENCES

1. COLD WATER TREATMENT AND CLEAN-UP
2. GAS SIDE PURGE
3. VITIATOR FIRING AND GAS HEATING
4. HOT WATER CLEAN-UP
5. ROLL AND SYNCHRONIZE TURBINE-GENERATOR
6. PHASE IN MAIN COMBUSTOR
7. LOAD MHD GENERATOR
8. STABILIZE AT BASE LOAD

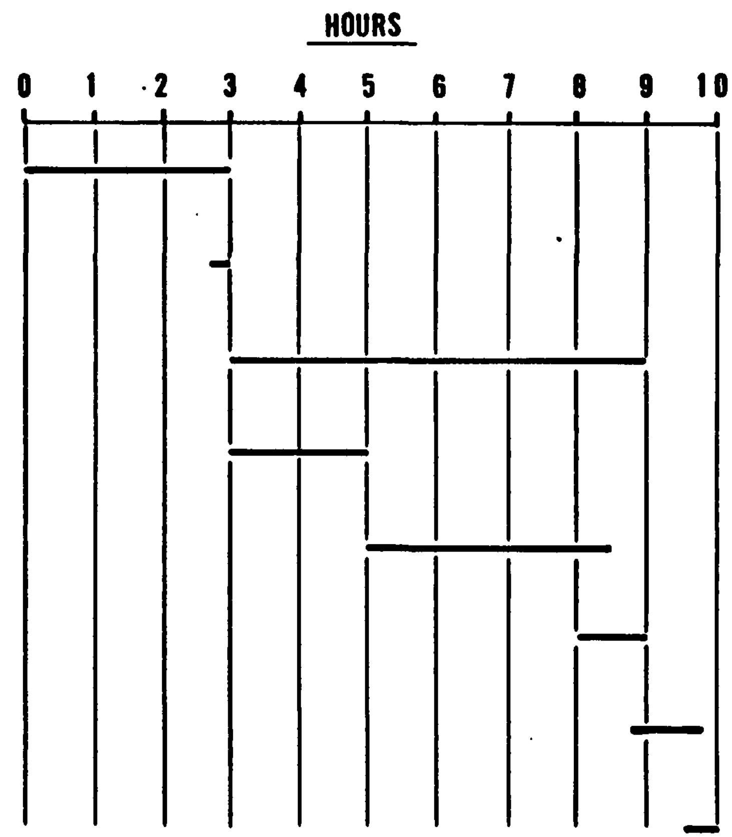


FIGURE 2-7
COLD START-UP SEQUENCES AND TIMES

FIGURE 2-8
TEMPERATURE LEVELS DURING
COLD START-UP



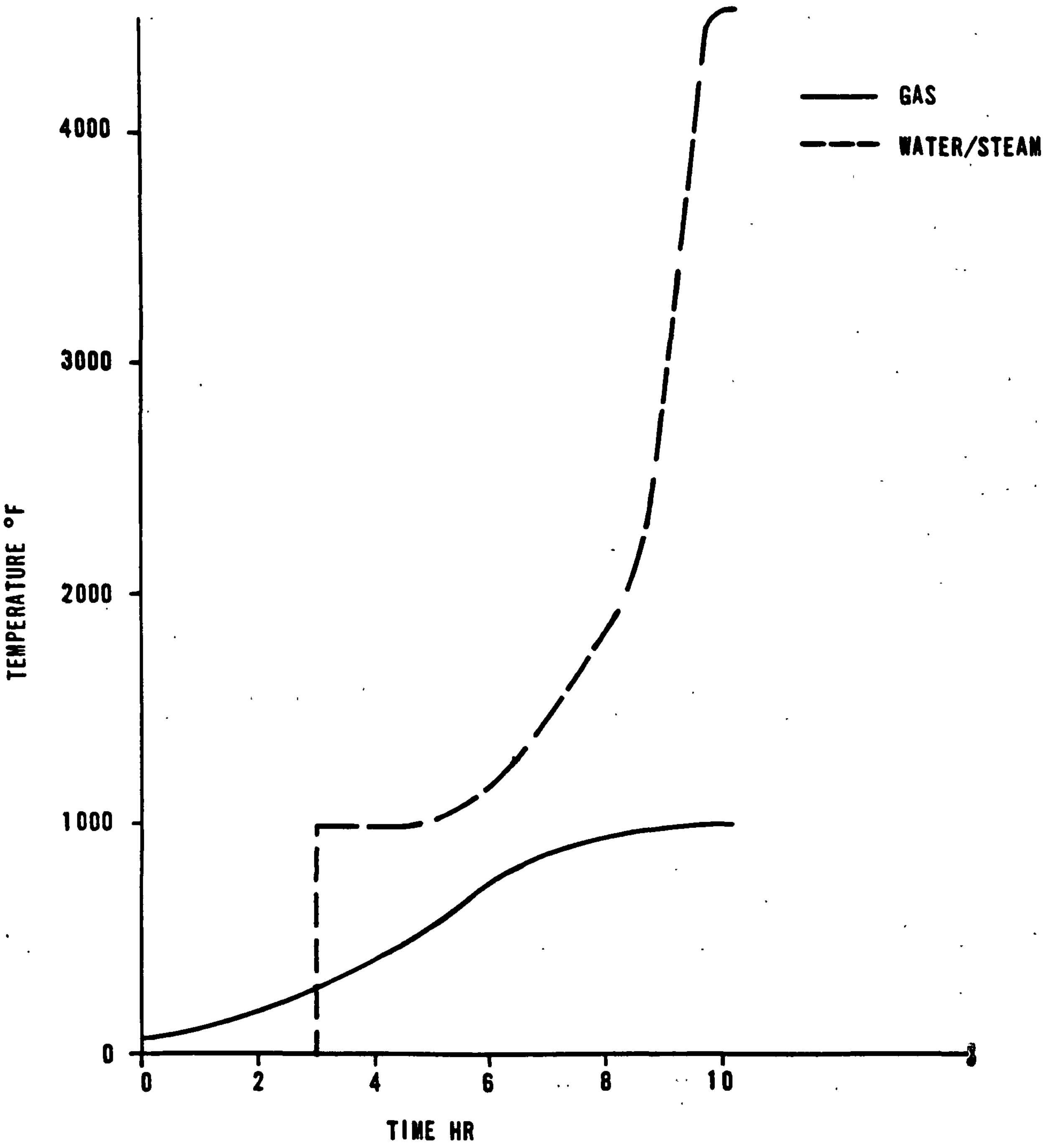

TABLE 2-15
BASELOAD OPERATING CONDITIONS

| | 100% Rating | 75% Rating |
|---|---|---|
| Plasma Flow Rate, lb/h | 1,048,589 | 786,000 |
| Combustor Heat Loss, MWt | 24.8 | 24.7 |
| Combustor Exit Pressure, psia | 66.4 | 48.5 |
| Combustor Exit Temperature, °F | 4,380 | 4,312 |
| Channel Heat Loss, MWt | 22.9 | 17.8 |
| MHD Power, MWe | 87.1 | 63.0 |
| Channel Exit Temperature, °F | 3,440 | 3,546 |
| Channel Exit Pressure, psia | 9.7 | 10.6 |
| Enthalpy Extraction, % | 18.5 | 17.7 |
| Diffuser Heat Loss, $MW_t$ | 26.5 | 22.9 |
| Diffuser Exit Temperature, °F | 3,532 | 3,474 |
| Diffuser Exit Pressure, psia | 13.0 | 13.0 |
| Thermal Input, $MW_t$ | 532 | 399 |

### 2.6.3 Transient

A dynamic analysis of the ETF has not been performed. However, for test and prototype operation the power plant must routinely follow demand transients, startup and shutdown sequences, and provide stable power.

Operation of the bottoming cycle (except for the HR/SR) can be modeled from conventional steam plant experience and should present no unusual problems. However, control systems for the dual cycle ETF must satisfy parameters imposed by the MHD cycle.

### 2.6.4 Shutdown

Planned shutdown will be a programmed procedure of the ETF. Flow of fuel, seed, and oxidant, as well as oxygen enrichment will be monitored and regulated to avoid temperature excursions or overpressure conditions through the channel or HR/SR. Sequences to curtail power from a design load condition are:

1. Reduce fuel and oxidant input rate with coordinated reduction in oxidant pressure. Temperatures would be maintained with normal oxygen enrichment. Seed flow would continue and channel power would be generated. System output would drop below 75 percent.



C-2

2. Continue to reduce flows from below the 75 percent design condition to 25 percent mass flow at a 1-1/2 percent flow reduction per minute. When oxidant pressure reduces to 2 atmospheres, oxygen enrichment will be discontinued and seed flow rate will be reduced (below the 1 percent mass flow point).

3. At the 25 percent mass flow rate and with gas temperatures reduced to the 2,200°F level (by addition of excess air) coal flow will be phased out and the vitiator phased in.

4. Depending on intent of shutdown, whether for long term (greater than a week) or short term, power systems will be secured accordingly for the succeeding startup.

It is expected that power shutdown can be accomplished in 4 hours.

### 2.6.5 Malfunction Procedures

A failure modes analysis imposes the most severe examination of power systems. Such an analysis requires that the plant be brought to a secure state within acceptable standards of risk to operating personnel and equipment. Prior safety analyses, failure modes and effects analyses, and established power plant procedures eliminate personnel access to areas of danger Procedures for postulated malfunctions have also been established. Failure modes in the MHD cycle and the responses include:

1. Coal Injection

   Oxidant flow and pressure would be reduced. Vitiator firing would maintain a hot standby condition. Multiple injection ports minimize complete fuel stoppage.

2. Seed Injection

   Sudden stoppage of seed flow could endanger the channel-diffuser and HR/SR and create hazards for personnel. Fuel flow rate and oxidant flow rate and pressure would be reduced. Oxygen flow would be stopped. The vitiator would replace main combustion for a prolonged outage. Multiple injection ports minimize complete seed stoppage.

3. Oxidant Injection

   Stoppage of oxidant flow would result in corresponding curtailment of fuel flow. Damage to the oxidant heater could be severe. Redundant compressors minimize complete oxidant loss.

For major failure modes such as main pipe rupture, turbine blade failure, key instrumentation loss, and meteorological disturbance, the turbine would experience an emergency trip. The plant design includes a 50 percent steam bypass. Trip from high load would result in relief and safety valve opening and vent to atmosphere.

## 2.7 MAINTENANCE, LOGISTICS, AND SECURITY

### 2.7.1 Logistics

The ETF requires a programmed supply of fuel, oxidant, compressed air, seed, water, chemicals, lubricants, industrial gases, maintenance, and housekeeping supplies.

The primary fuel, coal, is the greatest logistical problem. Transportation to the site is by rail and a 60 day supply of raw coal for full load firing is stored on site to ensure continuity of supply. In an emergency the site can accommodate supplemental delivery by using plant roads for coal truck delivery. At full load the plant requires 2,500 tons of raw coal per day.

Seed is delivered to the site in sealed railroad cars to prevent the absorption of moisture and stored in a moisture isolated environment. A ten day supply of fresh seed is maintained on site. Quantities of seed brought in depends on the seed management techniques employed on site for seed recovery and recycling. New seed as $K_2CO_3$ is required at a rate of 100 tons per day.

No. 2 grade fuel oil, used for startup or for emergency operation is normally delivered to the site by railroad tank cars. Facilities for railcar unloading are provided. Comparable facilities are also provided for backup delivery and unloading by truck. Fuel oil is used for auxiliary boilers, fire pump diesels, and emergency gas turbine generators. The main storage tank, located on site, holds a 30 day supply of 840,000 gallons (based on full load of all users). No. 2 fuel oil should be readily available but equipment design allows for acceptable operation on No. 3 fuel oil.

The compressed air for various requirements is supplied on site by air compressors. Oxygen, for enrichment of the compressed air, is supplied by an Air Separation Unit (ASU) installed on site. There are no external logistics involved with the oxygen or compressed air.

Water for fire protection and the filtered water system is provided from the Plant Makeup Water system and stored in a 400,000 gallon filtered water storage tank. Plant makeup water, some 4,000 gpm required to meet plant operating needs, should come from local lake or river sources. Studies on the impact of groundwater withdrawal will have to be performed. Potable water is expected to be supplied from on-site wells. A 300,000 gallon supply of raw water is provided and stored. With proper treatment it can be used for any plant purpose.

There are many different chemicals, oils, and greases to be delivered to the site by railroad and by trucks. Unloading areas and platforms are provided for receipt of materials. Procedures for handling these materials are well established and considered to be routine.

Industrial gases are brought in by special trucks and/or on tractor-trailers designed specifically for this purpose. Each gas has a specific unloading area to ensure that the delivered gas is stored in its assigned area.

Maintenance needs such as cleaning compounds, cements, gaskets, welding materials, and insulation are brought in by truck. For repair needs, parts are drawn from stock, where a computerized inventory system is maintained, or the parts are shipped to the site by truck, rail, or courier depending on the equipment size or urgency of need.

### 2.7.2 Maintenance and Replacement

The MHD-ETF Plant is designed with essentially the same maintenance considerations as a typical base load, coal-fired power plant except that additional, specialized features are included for maintenance and/or replacement of the topping side components. The maintenance concept for this base load demonstration plant is based on periodic surveillance of all operating equipment combined with scheduled maintenance outages for replacement of relatively short lived items, such as component packings, gaskets and seals.

#### 2.7.2.1 Design Features and Preventative Maintenance

The plant design incorporates various features for minimizing downtime associated with scheduled or unscheduled maintenance requirements. These features are outlined as follows:

1. Redundant components are provided for the powered equipment in all major systems (except for the Oxidant Supply System); e.g., three-50 percent boiler feed pumps, three-50 percent coal drying fans, three-50 percent transport gas compressors, etc. With this redundancy feature, maintenance can be performed on any given powered component while the ETF plant is operating at full load. In addition, the reliability of plant operation is significantly increased since the total operating life of each powered component is divided among several redundant units. In the Oxidant Supply System, only one ASU air compressor is provided because of the inherently high operational reliability of this type of proven air compressor. Stored liquid oxygen is available for backup supply for a limited period of operation.

2. Laydown and access spaces are provided for repair or replacement of all major replaceable components. This includes the special space provisions for rolling aside the magnet for access to and replacement of the channel. For non-replaceable components, such as the radiant boiler, access platforms are provided for accessibility to any component subassembly.

3. Computerized and programmed maintenance will be used for all active components. Pertinent performance data including tabulated losses and deviations from standard are recorded and made available to operators for easy reference and to identify any problems before they become critical. Work schedules are determined on the basis of equipment design and updated based on operating data. Maintenance records will be kept up to date.

4. Traveling bridge cranes are provided in all the major buildings (with the exception of the HR/SR Building) for handling of the larger plant components. Mobile cranes will be used for equipment for which frequent service is not expected.

5. Warehouse and machine shop facilities are provided as part of the overall maintenance program. A fully equipped machine shop and staff will be maintained so that some of the plant components can be accepted for machining, welding, or other required repair work. The warehouse provides storage for a complete computerized inventory of spare parts and repair materials to minimize system downtime.

6. A complete file of manufacturers' instruction books is available on site to guide the plant personnel in the maintenance and overhaul of any piece of equipment. If necessary, a representative of the manufacturer can be present to supervise the overhaul or replacement of plant equipment.

7. Preventative maintenance procedures are to be established to satisfy specific needs of individual components. These include the following:

    Specific maintenance operations to be performed.

    Maintenance frequencies.

    Required system conditions (e.g., normal, shutdown).

    Outlines of maintenance procedures.

    Definitive restrictions, special tools, and provisioning requirements.

    Preventative maintenance operations, such as inspections, calibrations, routine performance tests, electrical testing, lubrication, replacement, adjustments, and the like are to be performed periodically for the purpose of maintaining efficient and safe operation of the plant systems. Work schedules will be determined on the basis of equipment design and updated from actual operating experience.

#### 2.7.2.2 Routine and Operational Maintenance

The following provisions are incorporated in the design and layout of the MHD power train and adjacent area for routine and operational maintenance.

1. Combustor and Magnet Service Area

    A traveling bridge crane is located in the magnet area to assist in the disassembly, maintenance, and assembly of large components. Laydown space is provided east of the magnet location. Crane capacity is determined by the heaviest piece to be handled after initial assembly. A rail spur is provided into this area.

2. Channel

Special provisions for removing the channel from the magnet assembly are incorporated into the plant design. These provisions, as shown on Layout Drawing No. 8270-1-310-010-001, allow for rolling of the magnet away from the MHD Power Train and then removal of the channel from the magnet utilizing the channel removal fixture and channel support fixture. For channel replacement, the channel support fixture is designed to transport the old and new channels between the magnet assembly and the railroad car that is on the spur line in this area. If necessary, the channel can be placed in the laydown space adjacent to the magnet for repairs.

3. Diffuser/Transition Section

The diffuser/transition section can be disassembled and removed by an overhead crane. Adjacent laydown space is provided, or the sections can be removed by rail car on the rail spur provided in the area.

4. Radiant Boiler

The radiant boiler will be furnished with access platforms at all elevations required for access to boiler subassemblies. Platforms will allow for "shift" operations, such as visual inspections (observation ports, etc.) and soot blower maintenance.

Tube leaks will be handled either from existing platforms or through the use of temporary scaffolding from which the required repair work will be done.

5. Recuperative Heat Exchangers

No customized provisions have been incorporated for the superheater, reheater, intermediate temperature oxidant heater, or economizers. As required, sections will be removed for repair. Since the gas side is expected to be more erosive - corrosive than in conventional service, generous space allotments are being made for soot blowers and access aisles.

6. ASU and Oxidant Compressors

These compressors are located in the Air and Oxidant Compressor Building. A traveling bridge crane, sized for the heaviest component after initial erection, runs the entire length of the area parallel to shaft centerlines. The compressor casing is split horizontally and ample laydown area (and substantial operating redundancy) are provided.

7. Turbine Generator Building

Turbine Generator building maintenance will be conventional. The area is enclosed and is supplied with a bridge crane capable of handling the largest component after initial erection. Included in the main turbine area are the turbine driven and motor driven boiler feed pump assemblies. Casings are split horizontally and the machinery can be serviced by the

area bridge crane. Ample laydown space has been allotted to ensure that maintenance of "scheduled" equipment can be performed within acceptable downtimes for conventional systems.

Auxiliary apparatus, pumps, and heat exchangers are located below the T-G operating floor level. Aisles for fork lifts, dollies, and field assembled "A" frames are provided to facilitate overhaul of these smaller units.

8. Indoor (Ready) Coal Handling Area

A mobile crane and a monorail system will be utilized to assist in maintenance of pulverizing mill equipment. Sufficient aisle space will facilitate crane maneuvering. The pulverizers have relatively high frequency maintenance requirements. Coal feeders located above the pulverizing mills have adequate clearance for belt changing and routine inspection and servicing.

The bunker loading system is proven equipment. A monorail will be used to remove conveyor drive gears, head pulleys and motor drives for repair or replacement.

#### 2.7.2.3 Shutdown Maintenance Schedules

Equipment shutdown schedules will be determined from the design and construction records of equipment by analyzing the operating conditions to be expected. In particular, the high temperature MHD equipment will be reviewed for slagging, deposits, and damage. Schedules will be modified based on operating experience.

### 2.7.3 Security

Power plant owners, the licensing agencies and the operating and supervising personnel have recognized and established the need for rigorous plant security. Of major concern are the huge capital costs of equipment, the burdensome expenses of plant downtime, safety of plant personnel and obligations to plant customers and the public at large. In recent years, power plants have become targets of special interest activist groups. Plant security personnel must be trained and have the capability to react to the extremes of terrorist action, as well as impromptu trespassing, authorized admission of plant employees, and supervised admission of the public.

#### 2.7.3.1 Personnel Access

Authorized access to the plant is controlled through guardhouses located at the inner security fence. The main guardhouse is a structure of approximately 2,400 square feet adjacent to the service building. Plant personnel will be admitted by badge identification. Visitors will be admitted after identification and verification of proper authorization for entry. Equipment is available for inspection of packages and vehicles as required. All visitors will be badged and permanent registration records kept. Escorts will be provided as applicable.

Guardhouses have backup facilities to prevent unauthorized access. Direct line communication with the main control room, plant supervision, patrolling guards and local government law enforcement agencies are provided. The site is enclosed by an outer security fence which defines the property area. An inner security fence encircles the plant area where active means are employed to prevent unauthorized intrusion. Vehicular access is controlled at the outer fence. Only individually authorized vehicular traffic will be allowed into plant areas.

#### 2.7.3.2 Internal Secure Areas

Vital internal areas are defined as those where deliberate or involuntary damage to equipment could result in major disruption of plant services and endangering area personnel. Vital internal areas include the main control room, the ETF power train and other elements of the power and supply systems. Admission to these areas is by closely supervised key card access. A special case of controlled access during power plant operation, is to the magnet area. Because of the intense magnetic fields generated, restriction zones for timed access, depending on the local field value, are monitored to ensure against violations. (See Section 2.5.3 for details of magnet restriction zones.)

## 2.8 DRAWINGS

### 2.8.1 Heat and Mass Balance Diagram

The System Heat and Mass Balance, Drawing No. 8270-1-540-314-001 is included as Appendix 2A.

### 2.8.2 GAI Drawing List

The current GAI Drawing List is attached as Appendix 2B. Copies of these drawings are included in the CDER in the following locations, in accordance with their functions.

1. The System Heat and Mass Balance is included in Appendix 2A.

2. Fluid System Diagrams and associated drawings are included in their respective system design descriptions, following Section 5.5.

3. The balance of the drawings listed in the GAI Drawing List (Appendix 2B) provide information which is relevant to the project conceptual design description, and present overall engineering information, but are not included with a specific system. For convenience, these drawings are listed and copies included in Appendix 2C, "Related Drawings."

## APPENDIX 2A

## HEAT AND MASS BALANCE DIAGRAM

Dwg. No. 8270-1-540-314-001, Rev. 1 System Heat and Mass Balance

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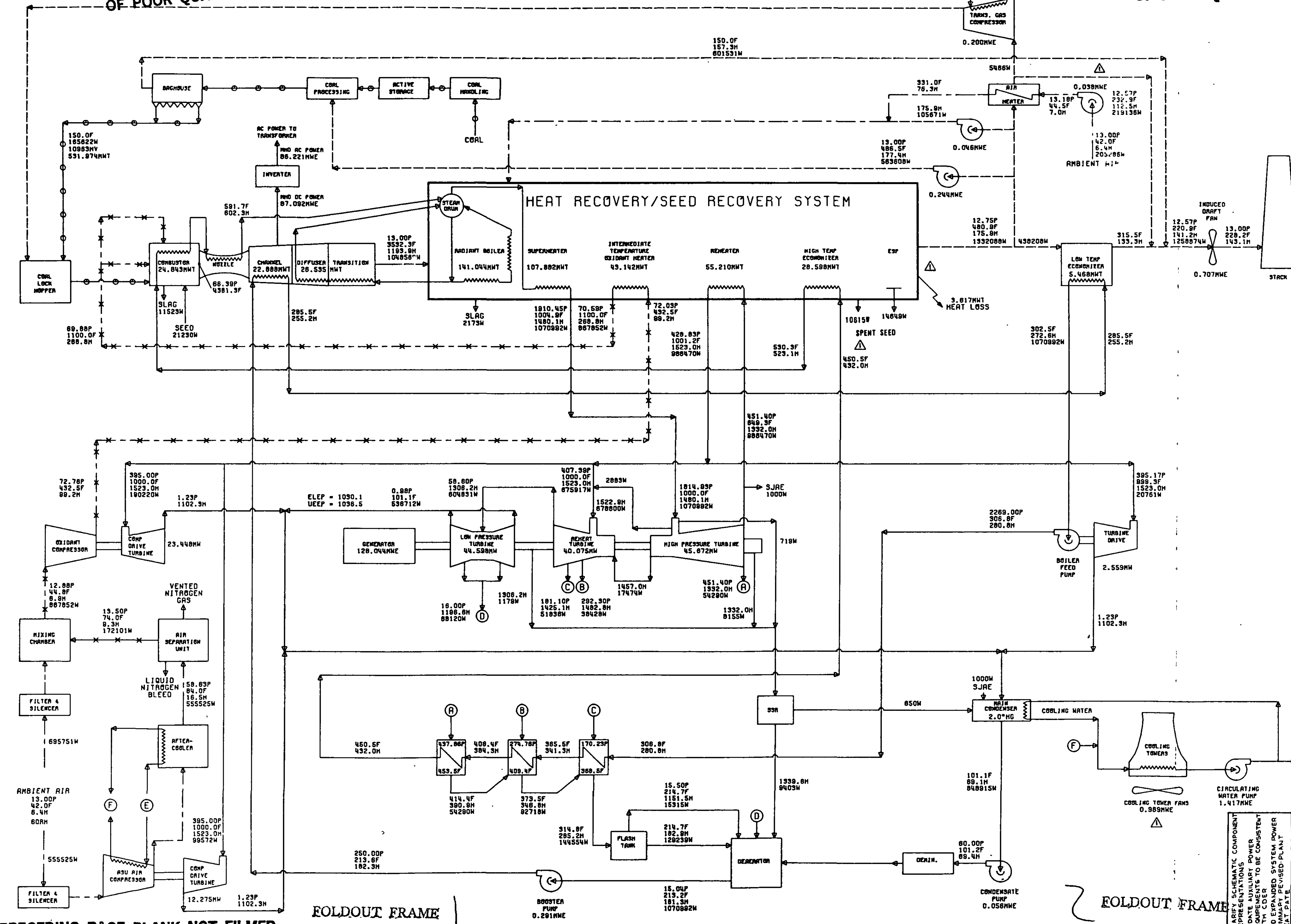


FOLDOUT FRAME

FOLDOUT FRAME

## LEGEND

- CONDENSATE, FEEDWATER AND STEAM
- OXYGEN
- OXYGEN ENRICHED AIR
- AIR
- COAL
- FLUE GAS

P - PRESSURE, PSIA
F - TEMPERATURE, DEG.F
H - ENTHALPY, BTU/LBM
W - MASS FLOW RATE, LBM/HR
MWT - MEGAWATTS, THERMAL
MWE - MEGAWATTS, ELECTRICAL
HV - HEATING VALUE, BTU/LBM
RH - RELATIVE HUMIDITY, %
ELEP - EXPANSION LINE END POINT, BTU/LBM
UEEP - USED ENERGY END POINT, BTU/LBM
ESP - ELECTROSTATIC PRECIPITATOR
SSR - STEAM SEAL REGULATOR
SJAE - STEAM JET AIR EJECTOR
MW - POWER, MEGAWATTS
GROSS POWER - TOTAL PLANT ELECTRICAL OUTPUT (MHD DC POWER + TURBINE GENERATOR)
AUXILIARIES - REQUIRED ACCESSORY POWER
NET POWER - POWER AVAILABLE TO UTILITY GRID

## NOTES

DESIGN POINT INPUT:
30 MOLE % O2 OXIDANT
12.1 METER ACTIVE CHANNEL LENGTH
3300 FT ALTITUDE
1100 DEG F OXIDANT PREHEAT

## ETF SYSTEM POWER SUMMARY

| | |
|---|---|
| MHD ELECTRICAL POWER: MWe | |
| MHD DC POWER OUTPUT | 87.1 |
| INVERTER/TRANSFORMER LOSS | -2.1 |
| MHD AC ELECTRICAL POWER OUTPUT | 85.0 |
| STEAM CYCLE ELECTRICAL POWER: MWe | |
| TOTAL STEAM SHAFT POWER | 168.6 |
| OXIDANT COMPRESSOR | -23.4 |
| ASU COMPRESSOR | -12.3 |
| BOILER FEED PUMP | -2.6 |
| NET SHAFT POWER | 130.3 |
| TURBOGENERATOR LOSS | -2.3 |
| ELECTRICAL POWER OUTPUT | 128.0 |
| GROSS PLANT ELECTRICAL OUTPUT: MWe | 213.0 |
| AUXILIARY POWER REQUIREMENTS: MWe | -10.8 |
| NET PLANT ELECTRICAL OUTPUT: MWe | 202.2 |
| PLANT EFFICIENCY: % | 38.0 |
| PLANT HEAT RATE: BTU/KW-HR | 8979.7 |

| | | |
|---|---|---|
| 3-27-81 | CONCEPTUAL DESIGN ISSUE | CJL |
| 3-9-81 | PRELIMINARY ISSUE | CJL |
| 10-3-80 | SOO ISSUE | RCW |
| DWG DATE | RELEASED FOR | ENGR |

MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

200 MWE MHD POWER PLANT SYSTEM HEAT AND MASS BALANCE

DOE - NASA

MHD PROJECT OFFICE — APPD. H. RIGO
LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135 — DATE 9-25-81

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA

REVISIONS: 1 — CLARIFY SCHEMATIC COMPONENT REPRESENTATIONS; UPDATE AUXILIARY POWER REQUIREMENTS TO BE CONSISTENT WITH CDER; ADD EXPANDED SYSTEM POWER SUMMARY PER REVISED PLANT HEAT RATE — 9-25-81

SCALE N.T.S. — 8270-1-540-314-001 — REV 1

W.O. 08-8270-303 — DRAWING NUMBER

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# APPENDIX 2B

## GAI DRAWING LIST

The current GAI Drawing List is provided as follows:

| NUMBER | REV. | TITLE |
|---|---|---|
| 8270-1-001-600-001 | 1 | Drawing Index |
| | | POWER PLANT ARRANGEMENTS |
| 8270-1-210-007-001 | 1 | Plot Plan |
| 8270-1-240-002-001 | 1 | Yard Coal Handling - Plan and Section |
| 8270-1-240-002-002 | 1 | Yard Coal Handling - Plan and Sections |
| 8270-1-240-002-003 | 1 | Seed Unloading and Storage Area - Plan |
| 8270-1-240-002-004 | 1 | Seed Unloading and Storage Area - Section |
| 8270-1-300-010-002 | 1 | Heat Recovery Seed Recovery - Plan |
| 8270-1-300-010-003 | 1 | Heat Recovery Seed Recovery - Section |
| 8270-1-310-010-001 | 1 | MHD Building - Plan |
| 8270-1-310-010-002 | 1 | MHD Building - Section |
| 8270-1-320-002-001 | 1 | Air and Oxidant Compressor Building - Plan |
| 8270-1-320-002-002 | 1 | Air and Oxidant Compressor Building - Section |
| 8270-1-320-002-003 | 1 | Air Separation Unit - Plan |
| 8270-1-320-002-004 | 1 | Air Separation Unit - Section |
| 8270-1-380-010-001 | 1 | Turbine Generator Building, Basement Floor Plan |
| 8270-1-380-010-002 | 1 | Turbine Generator Building, Mezzanine Floor Plan |
| 8270-1-380-010-003 | 1 | Turbine Generator Building, Operating Floor Plan |
| 8270-1-380-010-004 | 1 | Turbine Generator Building, Section |
| 8270-1-810-002-001 | 1 | Inverter and Switchgear Building - Plan, 0'-6" |
| 8270-1-810-002-002 | 1 | Inverter and Switchgear Building - Section |
| 8270-1-810-002-003 | 1 | Inverter and Switchgear Building - Plan, 35'-6" |
| | | SYSTEM DIAGRAMS - SYMBOLS |
| 8270-1-500-302-001 | 1 | Symbols |
| | | FLUID SYSTEM DIAGRAMS - STEAM POWER SYSTEMS |
| 8270-1-491-302-131 | 1 | Condenser Air Removal |
| 8270-1-501-302-011 | 1 | Main and Reheat Steam |
| 8270-1-503-302-041 | 1 | Extraction Steam |
| 8270-1-511-302-101 | 1 | Condensate |
| 8270-1-519-302-121 | 1 | Miscellaneous Drains |
| 8270-1-521-302-081 | 1 | Boiler Feedwater |
| 8270-1-525-302-111 | 1 | Feedwater Heater Drips |
| 8270-1-525-302-113 | 1 | Feedwater Heater Vents, Drains and Reliefs |
| 8270-1-571-302-201 | 1 | Circulating and Service Water |

APPENDIX 2B (Cont'd)

| NUMBER | REV. | TITLE |
|---|---|---|
| | | FLUID SYSTEM DIAGRAMS - PLANT AUXILIARY SYSTEMS |
| 8270-1-403-302-321 | 1 | Boiler Flue Gas |
| 8270-1-403-302-322 | 1 | Afterburner Gas Supply |
| 8270-1-403-302-323 | 1 | Coal Drying and Transport Gas |
| 8270-1-410-302-341 | 1 | Coal Feed Lock Hoppers |
| 8270-1-410-302-342 | 1 | Seed Feed Lock Hoppers |
| 8270-1-451-302-351 | 1 | Slag Handling |
| 8270-1-451-302-352 | 1 | Ash/Seed Removal From Power Systems (Fluid Gas Cleanup) |
| 8270-1-507-302-051 | 1 | Auxiliary Steam |
| | | FLUID SYSTEM DIAGRAMS - PLANT SERVICE SYSTEMS |
| 8270-1-413-302-281 | 1 | Fuel Oil |
| 8270-1-531-302-231 | 1 | Closed Cycle Cooling Water - Turbine and Compressor Building |
| 8270-1-531-302-232 | 1 | Closed Cycle Cooling Water - HR/Sr Area and MHD Building |
| 8270-1-582-302-161 | 1 | Plant Make-Up Water |
| 8270-1-633-302-181 | 1 | Sampling |
| 8270-1-641-302-371 | 1 | Plant Industrial Waste |
| 8270-1-644-302-381 | 1 | Sanitary Waste |
| 8270-1-652-302-241 | 1 | Plant Service and Instrument Air Supply |
| 8270-1-652-302-242 | 1 | Miscellaneous Gases |
| 8270-1-721-902-001 | 1 | HVAC - Chilled Water |
| 8270-1-722-902-001 | 1 | HVAC - Steam - Hot Water |
| 8270-1-781-902-401 | 1 | Fire Service Water |
| | | FLUID SYSTEM DIAGRAMS - SYSTEM HEAT AND WATER BALANCES |
| 8270-1-540-314-001 | 1 | System Heat Balance |
| 8270-1-550-318-001 | 1 | Water Balance |
| | | ONE-LINE DIAGRAMS - ELECTRICAL |
| 8270-1-802-206-001 | 1 | Primary Power |
| 8270-1-802-206-002 | 1 | 4160 V Power |
| 8270-1-802-206-003 | 1 | 480 V Power |

## APPENDIX 2C

## RELATED DRAWINGS

The following drawings, listed in Appendix 2B, provide information which is relevant to the project conceptual design description since they are not included with a specific system, they are provided in this Appendix:

| NUMBER | REV. | TITLE |
|---|---|---|
| 8270-1-001-600-001 | 1 | Drawing Index |
| 8270-1-210-007-001 | 1 | Plot Plan |
| 8270-1-300-010-002 | 1 | Heat Recovery Seed Recovery - Plan |
| 8270-1-300-010-003 | 1 | Heat Recovery Seed Recovery - Section |
| 8270-1-310-010-001 | 1 | MHD Building - Plan |
| 8270-1-310-010-002 | 1 | MHD Building - Section |
| 8270-1-320-002-001 | 1 | Air and Oxidant Compressor Building - Plan |
| 8270-1-320-002-002 | 1 | Air and Oxidant Compressor Building - Section |
| 8270-1-320-002-003 | 1 | Air Separation Unit - Plan |
| 8270-1-320-002-004 | 1 | Air Separation Unit - Section |
| 8270-1-380-010-001 | 1 | Turbine Generator Building, Basement Floor Plan |
| 8270-1-380-010-002 | 1 | Turbine Generator Building, Mezzanine Floor Plan |
| 8270-1-380-010-003 | 1 | Turbine Generator Building, Operating Floor Plan |
| 8270-1-380-010-004 | 1 | Turbine Generator Building, Section |
| 8270-1-810-002-001 | 1 | Inverter and Switchgear Building - Plan, 0'-6" |
| 8270-1-810-002-002 | 1 | Inverter and Switchgear Building - Section |
| 8270-1-810-002-003 | 1 | Inverter and Switchgear Building - Plan, 35'-6" |
| 8270-1-500-302-001 | 1 | Symbols (Fluid System & Electrical Deiagrams) |
| 8270-1-550-318-001 | 1 | Water Balance |

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| DRAWING NO. | DESCRIPTION |
|---|---|
| 8270-1-001-600-001 | DRAWING INDEX |
| | **POWER PLANT ARRANGEMENTS** |
| 8270-1-210-007-001 | PLOT PLAN |
| 8270-1-240-002-001 | YARD COAL HANDLING - PLAN AND SECTION (SDD-341) |
| 8270-1-240-007-002 | YARD COAL HANDLING - PLAN AND SECTIONS (SDD-341) |
| 8270-1-240-002-003 | SEED UNLOADING AND STORAGE AREA - PLAN (SDD-342) |
| 8270-1-240-002-004 | SEED UNLOADING AND STORAGE AREA - SECTION (SDD-342) |
| 8270-1-300-010-002 | HEAT RECOVERY SEED RECOVERY - PLAN |
| 8270-1-300-010-003 | HEAT RECOVERY SEED RECOVERY - SECTION |
| 8270-1-310-010-001 | MHD BUILDING - PLAN |
| 8270-1-310-010-002 | MHD BUILDING - SECTION |
| 8270-1-320-002-001 | AIR AND OXIDANT COMPRESSOR BUILDING - PLAN |
| 8270-1-320-002-002 | AIR AND OXIDANT COMPRESSOR BUILDING - SECTION |
| 8270-1-320-002-003 | AIR SEPARATION UNIT - PLAN |
| 8270-1-320-002-004 | AIR SEPARATION UNIT - SECTION |
| 8270-1-380-010-001 | TURBINE GENERATOR BUILDING, BASEMENT FLOOR PLAN |
| 8270-1-380-010-002 | TURBINE GENERATOR BUILDING, MEZZANINE FLOOR PLAN |
| 8270-1-380-010-003 | TURBINE GENERATOR BUILDING, OPERATING FLOOR PLAN |
| 8270-1-380-010-004 | TURBINE GENERATOR BUILDING, SECTION |
| 8270-1-810-002-001 | INVERTER AND SWITCHGEAR BUILDING - PLAN, 0'-6" |
| 8270-1-810-002-002 | INVERTER AND SWITCHGEAR BUILDING - SECTION |
| 8270-1-810-002-003 | INVERTER AND SWITCHGEAR BUILDING - PLAN, 35'-6" |

| DRAWING NO. | DESCRIPTION |
|---|---|
| | **SYSTEM DIAGRAMS - SYMBOLS** |
| 8270-1-500-302-001 | SYMBOLS |
| | **FLUID SYSTEM DIAGRAMS-STEAM POWER SYSTEMS** |
| 8270-1-491-302-131 | CONDENSER AIR REMOVAL (SDD-131) |
| 8270-1-501-302-011 | MAIN AND REHEAT STEAM (SDD-011) |
| 8270-1-503-302-041 | EXTRACTION STEAM (SDD-041) |
| 8270-1-504-302-031 | STEAM BY-PASS AND START-UP (SDD-031) |
| 8270-1-511-302-101 | CONDENSATE (SDD-101) |
| 8270-1-519-302-121 | MISCELLANEOUS DRAINS (SDD-113) |
| 8270-1-521-302-081 | BOILER FEEDWATER (SDD-081) |
| 8270-1-525-302-111 | FEEDWATER HEATER DRIPS (SDD-111) |
| 8270-1-525-302-113 | FEEDWATER HEATER VENTS, DRAINS AND RELIEFS (SDD-113) |
| 8270-1-571-302-201 | CIRCULATING AND SERVICE WATER (SDD-201) |
| | **FLUID SYSTEM DIAGRAMS - PLANT AUXILIARY SYSTEMS** |
| 8270-1-403-302-321 | BOILER FLUE GAS (SDD-321) |
| 8270-1-403-302-322 | AFTERBURNER GAS SUPPLY (SDD-321) |
| 8270-1-403-302-323 | COAL DRYING AND TRANSPORT GAS (SDD-321) |
| 8270-1-410-302-341 | COAL FEED LOCK HOPPERS (SDD-341) |
| 8270-1-410-302-342 | SEED FEED LOCK HOPPERS (SDD-342) |
| 8270-1-451-302-351 | SLAG HANDLING (SDD-351) |
| 8270-1-451-302-352 | ASH/SEED REMOVAL FROM POWER SYSTEMS (FLUE GAS CLEANUP) (SDD-342) |
| 8270-1-507-302-051 | AUXILIARY STEAM (SDD-051) |

| DRAWING NO. | DESCRIPTION |
|---|---|
| | **FLUID SYSTEM DIAGRAMS-PLANT SERVICE SYSTEMS** |
| 8270-1-413-302-281 | FUEL OIL (SDD-281) |
| 8270-1-531-302-231 | CLOSED CYCLE COOLING WATER - TURBINE AND COMPRESSOR BUILDING (SDD-231) |
| 8270-1-531-302-232 | CLOSED CYCLE COOLING WATER - H./SR AREA AND MHD BUILDING (SDD-231) |
| 8270-1-582-302-161 | PLANT MAKE-UP WATER (SDD-161) |
| 8270-1-633-302-181 | SAMPLING (SDD-181) |
| 8270-1-641-302-371 | PLANT INDUSTRIAL WASTE (SDD-371) |
| 8270-1-644-302-381 | SANITARY WASTE (SDD-371) |
| 8270-1-652-302-241 | PLANT SERVICE AND INSTRUMENT AIR SUPPLY (SDD-241) |
| 8270-1-652-302-242 | MISCELLANEOUS GASES (SDD-241) |
| 8270-1-721-902-001 | HVAC - CHILLED WATER (SDD-701) |
| 8270-1-722-902-001 | HVAC - STEAM - HOT WATER (SDD-701) |
| 8270-1-781-902-401 | FIRE SERVICE WATER (SDD-401) |
| | **FLUID SYSTEM DIAGRAMS-SYSTEM HEAT AND WATER BALANCES** |
| 8270-1-540-314-001 | SYSTEM HEAT BALANCE |
| 8270-1-550-318-001 | WATER BALANCE |
| | **ONE LINE DIAGRAMS - ELECTRICAL** |
| 8270-1-802-206-001 | PRIMARY POWER (SDD-801) |
| 8270-1-802-206-002 | 4160V POWER (SDD-801) |
| 8270-1-802-206-003 | 480V POWER (SDD-801) |

FOLDOUT FRAME

FOLDOUT FRAME

I.D. NO. C-373-053

| DATE | RELEASED FOR | ENGR. |
|---|---|---|
| 3-27-81 | CONCEPTUAL DESIGN ISSUE | |
| 3-17-81 | PRELIMINARY ISSUE | |

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

DRAWING INDEX

200 MWe

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MHD PROJECT OFFICE
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

APPD. H RIGO
DATE 9-25-81

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

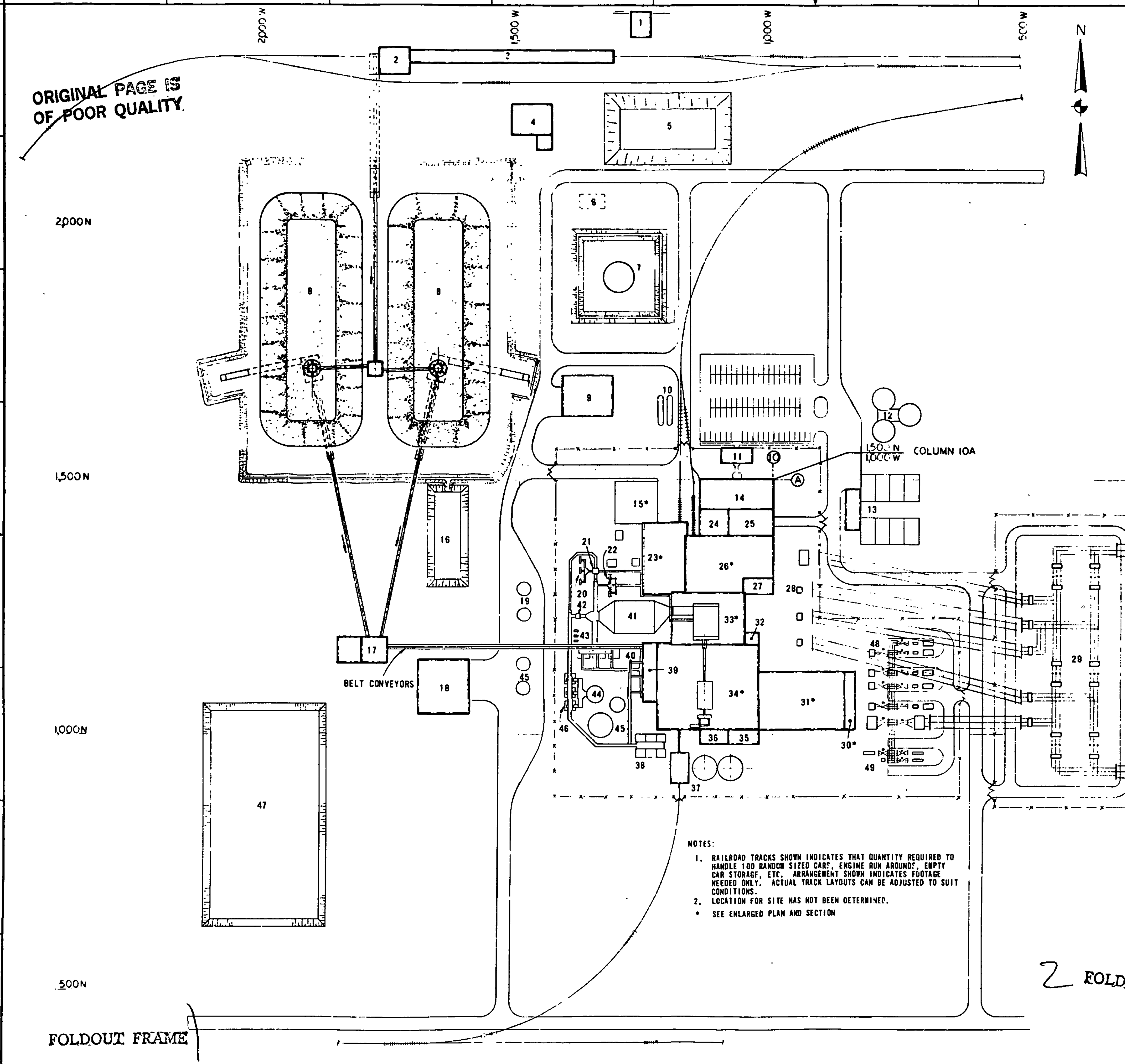
REVISIONS: 1 — ADDED PREFIX 8270-1 TO ALL DRAWING NUMBERS & SDD NOS. & H.RIGO DATE IN TITLE BLOCK — NL — 8-10-81

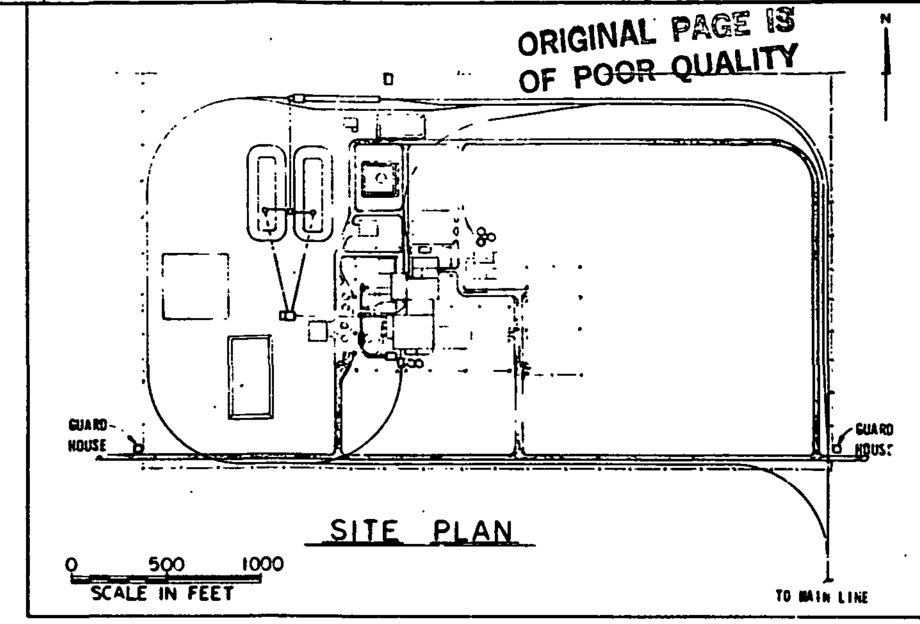
MADE G.K.

SCALE NONE

DRAWING NUMBER 8270-1-001-600-001 REV 1

W.O. 088270-201




LEGEND

1. INTAKE STRUCTURE
2. ROTARY CAR DUMPER
3. CAR THAWING SHED
4. COAL SYSTEM CONTROL BUILDING
5. STORMWATER RUNOFF BASIN
6. OIL/WATER SEPARATOR
7. FUEL OIL TANK, DIKE AND PUMP HOUSE
8. 30 DAYS COAL PILE STORAGE (EACH)
9. WAREHOUSE
10. LIQUID OXYGEN TANKS
11. MAIN GUARD HOUSE
12. STORAGE TANKS-FILTERED, FIRE SERVICE, RAW WATER AND CONDENSATE
13. COOLING TOWERS
14. ADMINISTRATION, SERVICE AND MACHINE SHOP
15. AIR SEPARATION UNIT
16. COAL PILE RUNOFF BASIN
17. YARD COAL CRUSHER HOUSE
18. SANITARY, INDUSTRIAL WASTE SLUDGE TREATMENT BUILDING
19. SPENT SEED AND FLY ASH SILOS
20. AFTERBURNER GAS FANS
21. AIR HEATER
22. FLUE GAS RECYCLE FANS
23. AIR AND OXIDANT COMPRESSOR BUILDING
24. AUXILIARY BOILER BUILDING
25. WATER TREATMENT AND DEMINERALIZATION BLDG.
26. TURBINE - GENERATOR BUILDING
27. CONTROL COMPLEX
28. TRANSFORMERS
29. SWITCHYARD
30. SWITCHGEAR BUILDING
31. INVERTER BUILDING
32. MISCELLANEOUS GAS STORAGE BUILDING
33. HEAT AND SEED RECOVERY BUILDING
34. MHD BUILDING
35. SEED FEED BUILDING
36. COAL FEED BUILDING
37. SEED UNLOADING FACILITY
38. BAGHOUSE
39. COAL PREPARATION BUILDING
40. COAL DRYING FANS
41. ELECTROSTATIC PRECIPITATOR
42. LOW TEMPERATURE ECONOMIZER
43. TRANSPORT GAS COMPRESSORS
44. CHIMNEY
45. DEWATERING BINS, SETTLING & SURGE TANKS
46. I.D. FANS
47. SLAG DISPOSAL POND
48. HARMONIC FILTERING
49. POWER FACTOR CORRECTION

NOTES:

1. RAILROAD TRACKS SHOWN INDICATES THAT QUANTITY REQUIRED TO HANDLE 100 RANDOM SIZED CARS, ENGINE RUN AROUNDS, EMPTY CAR STORAGE, ETC. ARRANGEMENT SHOWN INDICATES FOOTAGE NEEDED ONLY. ACTUAL TRACK LAYOUTS CAN BE ADJUSTED TO SUIT CONDITIONS.
2. LOCATION FOR SITE HAS NOT BEEN DETERMINED.

* SEE ENLARGED PLAN AND SECTION

I.D. NO. C-073-016

| | | |
|---|---|---|
| 3-27-81 | CONCEPTUAL DESIGN ISSUE | |
| 2-13-81 | PRELIMINARY ISSUE | |
| DATE | RELEASED FOR | ENGR. |

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

PLOT PLAN

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LEWIS RESEARCH CENTER
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APPD. H. RIGO
DATE 9-25-81

REVISIONS: 1 — ADDED H. RIGO & DATE TO TITLE BLOCK

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DRAWING NUMBER 8270-1-210-007-001 REV 1

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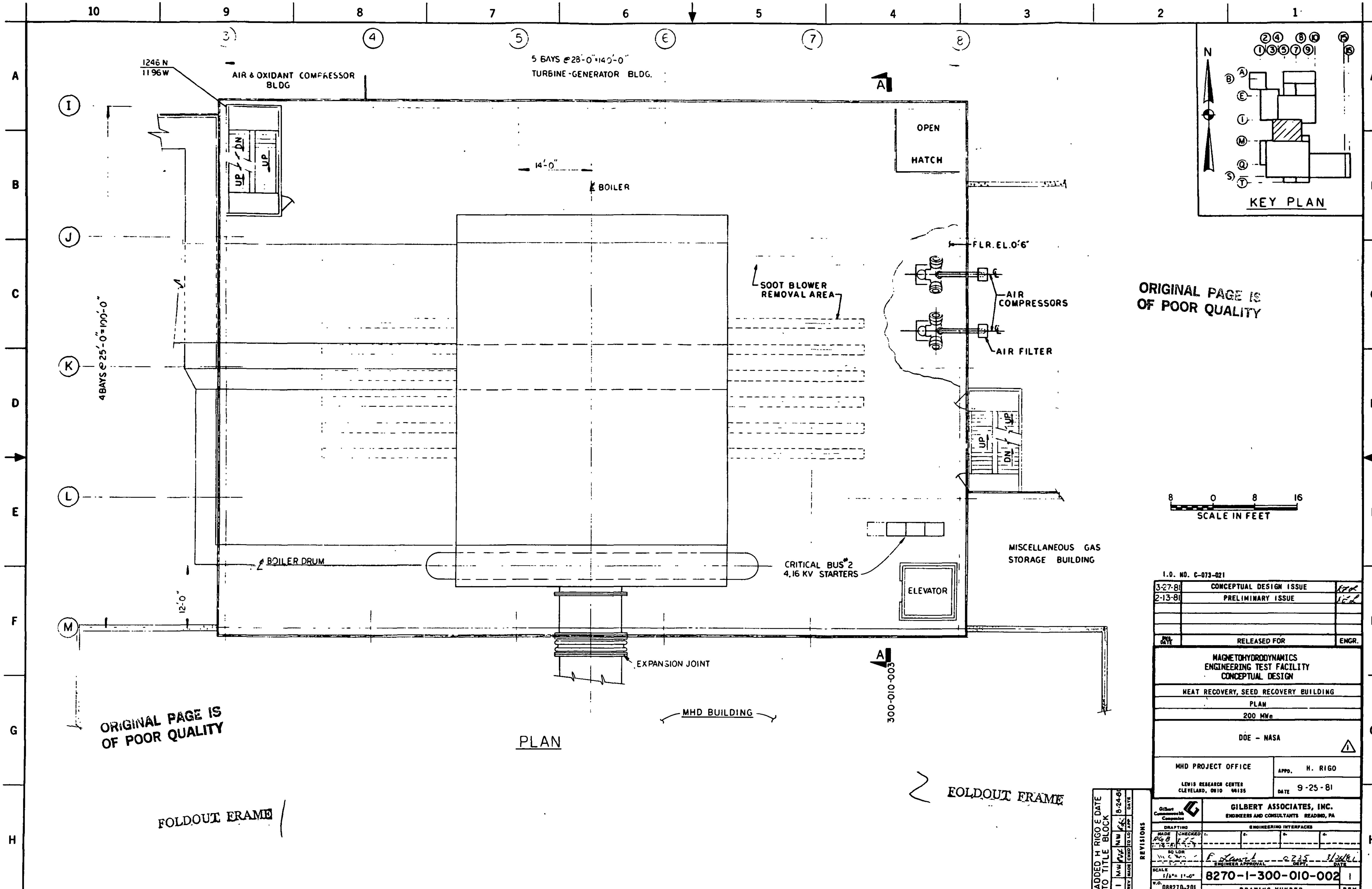




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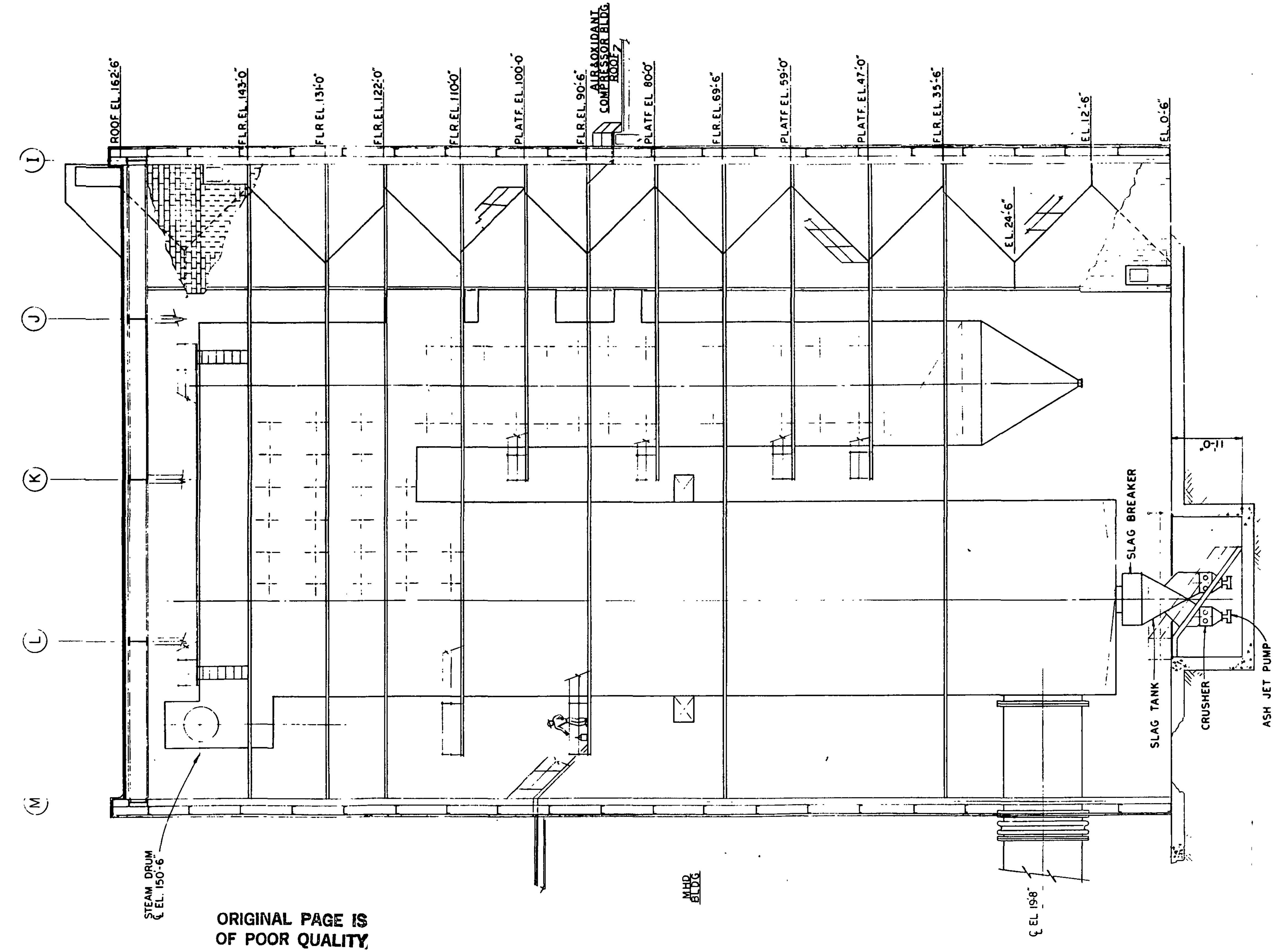


SECTION A-A
PLAN DWG. 300-010-002

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I.D. NO. C-073-822

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|---|---|---|
| 3-27-81 | CONCEPTUAL DESIGN ISSUE | CZL |
| 2-13-81 | PRELIMINARY ISSUE | CZL |

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

HEAT RECOVERY SEED RECOVERY BUILDING
SECTION
200 MWe

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LEWIS RESEARCH CENTER
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APPD. H. RIGO
DATE 9-25-81

| REV | MADE | CHKD | SQ LD | APP | DATE | REVISIONS |
|---|---|---|---|---|---|---|
| 1 | F | CZL | MW | CZL | 8-24-81 | ADDED H. RIGO & DATE TO TITLE BLOCK |

Gilbert Commonwealth Companies
GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA

DRAFTING: MADE DKR 1-23-81; CHECKED CZL
SQ LDR 2-25-81
ENGINEERING INTERFACES 1. 2. 3. 4.
ENGINEER APPROVAL — DEPT. 0715 — DATE 3/26/81
SCALE 1/8" = 1'-0"
W.O. 088270-201
DRAWING NUMBER 8270-1-300-010-003 REV 1

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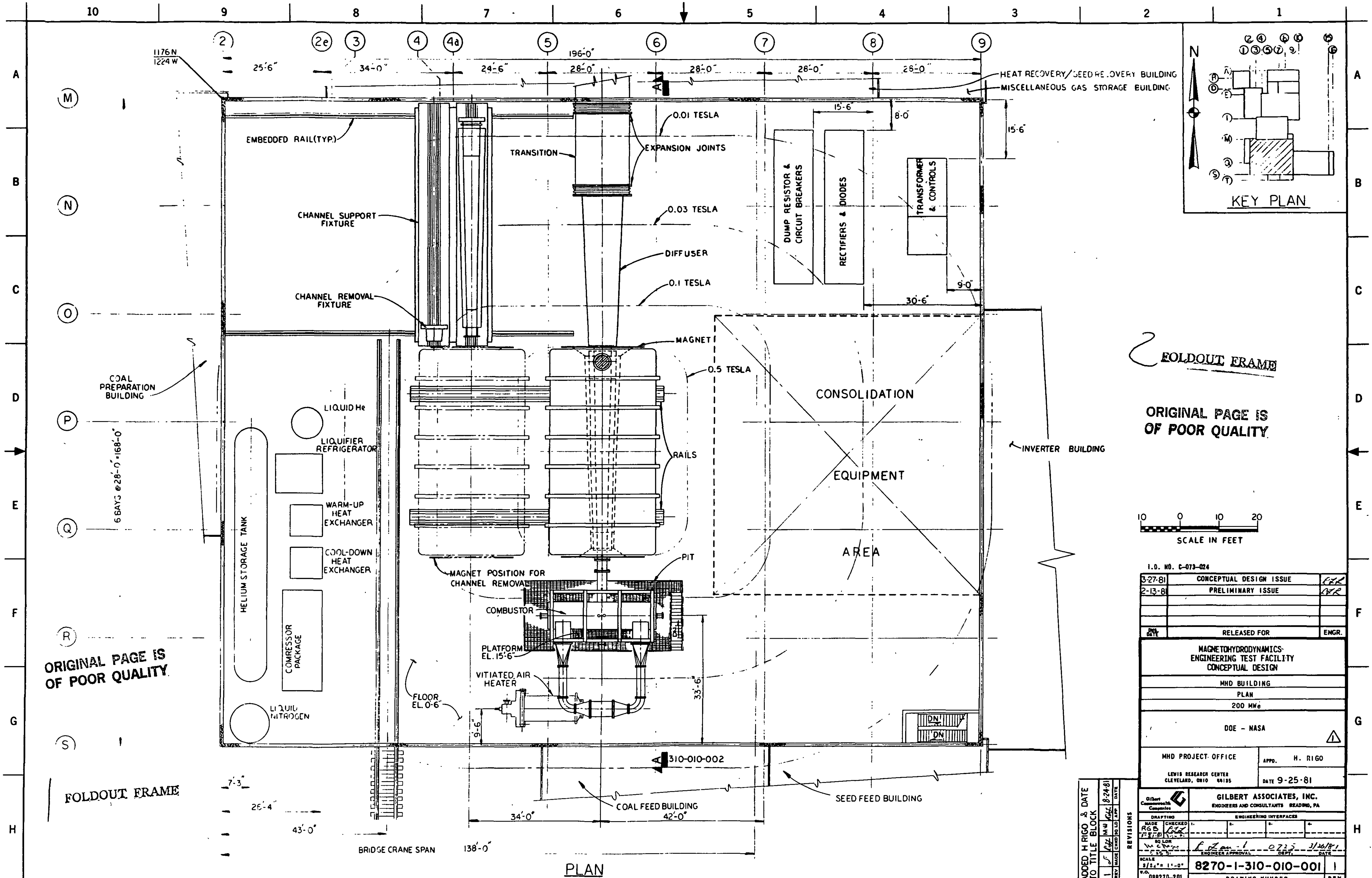
1176 N
1224 W
196'-0"
25'-6"
34'-0"
24'-6"
28'-0"
28'-0"
28'-0"
28'-0"
HEAT RECOVERY/SEED RECOVERY BUILDING
MISCELLANEOUS GAS STORAGE BUILDING
EMBEDDED RAIL (TYP.)
TRANSITION
0.01 TESLA
EXPANSION JOINTS
15'-6"
8'-0"
15'-6"
DUMP RESISTOR & CIRCUIT BREAKERS
RECTIFIERS & DIODES
TRANSFORMER & CONTROLS
CHANNEL SUPPORT FIXTURE
0.03 TESLA
DIFFUSER
0.1 TESLA
CHANNEL REMOVAL FIXTURE
9'-0"
30'-6"
MAGNET
0.5 TESLA
COAL PREPARATION BUILDING
LIQUID He
LIQUIFIER REFRIGERATOR
6 BAYS @ 28'-0" = 168'-0"
HELIUM STORAGE TANK
WARM-UP HEAT EXCHANGER
COOL-DOWN HEAT EXCHANGER
COMPRESSOR PACKAGE
LIQUID NITROGEN
RAILS
CONSOLIDATION
EQUIPMENT
AREA
INVERTER BUILDING
MAGNET POSITION FOR CHANNEL REMOVAL
PIT
COMBUSTOR
PLATFORM EL. 15'-6"
VITIATED AIR HEATER
FLOOR EL. 0'-6"
33'-6"
9'-6"
DN
DN
310-010-002
COAL FEED BUILDING
SEED FEED BUILDING
7'-3"
26'-4"
43'-0"
34'-0"
42'-0"
BRIDGE CRANE SPAN
138'-0"
PLAN
KEY PLAN
N
FOLDOUT FRAME
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SCALE IN FEET
I.O. NO. C-073-024
3-27-81 CONCEPTUAL DESIGN ISSUE
2-13-81 PRELIMINARY ISSUE
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MAGNETOHYDRODYNAMICS-ENGINEERING TEST FACILITY CONCEPTUAL DESIGN
MHD BUILDING
PLAN
200 MWe
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MHD PROJECT OFFICE
APPD. H. RIGO
LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135
DATE 9-25-81
ADDED H RIGO & DATE TO TITLE BLOCK
8-24-81
REVISIONS
GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS READING, PA
ENGINEERING INTERFACES
SCALE 3/32" = 1'-0"
8270-1-310-010-001
DRAWING NUMBER
REV
1

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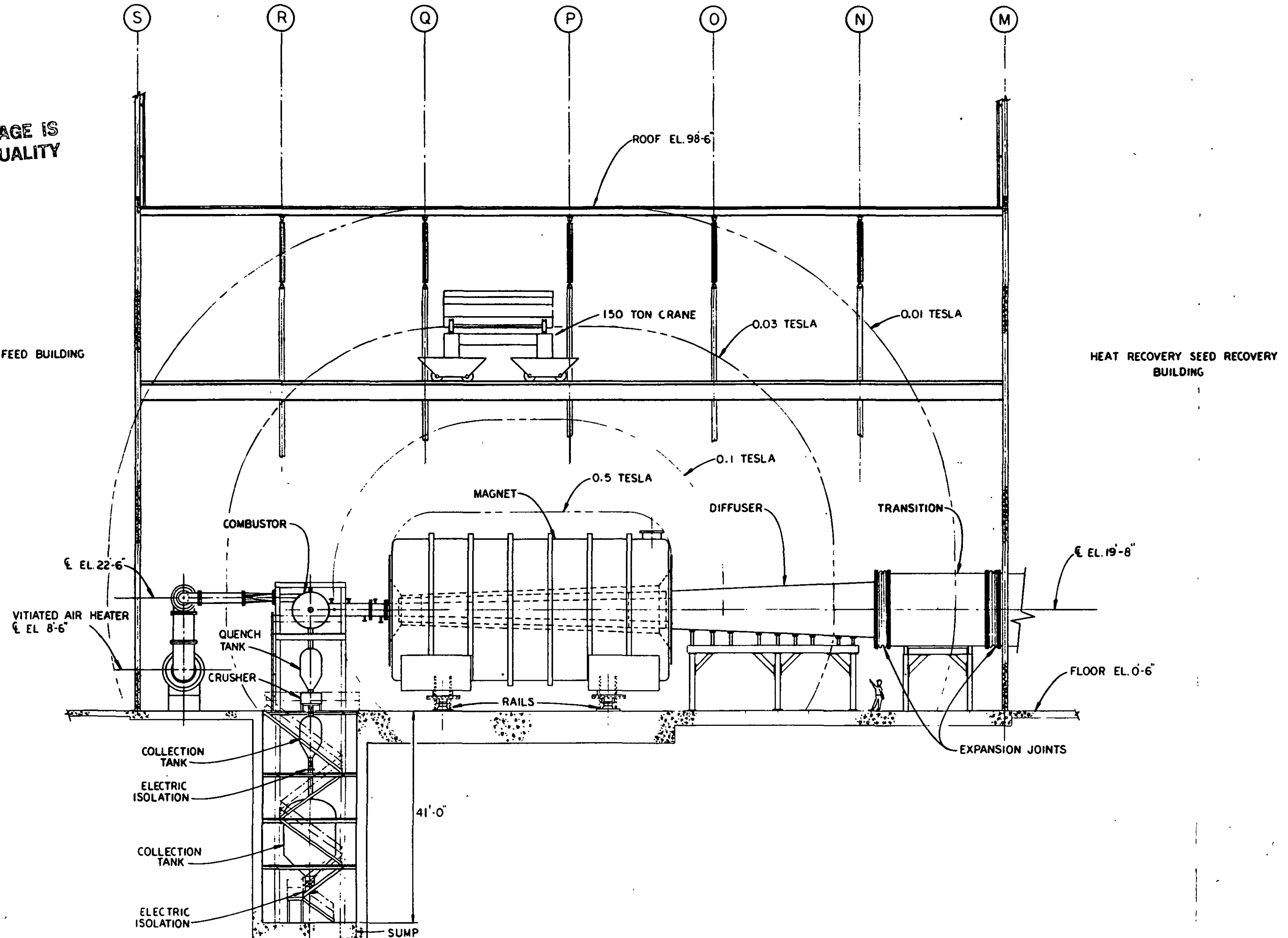


SECTION A-A

PLAN-DWG. 310-010-001

10 0 10 20

SCALE IN FEET

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I.D. NO. C-073-025

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| 3-27-81 | CONCEPTUAL DESIGN ISSUE | | 
| 2-13-81 | PRELIMINARY ISSUE | |
| DATE | RELEASED FOR | ENGR. |

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

MHD BUILDING
SECTION
200 MWe

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CLEVELAND, OHIO 44135

APPD. H. RIGO
DATE 9-25-81

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ENGINEERING INTERFACES

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W.O. 088270-201

8270-1-310-010-002 | REV 1

DRAWING NUMBER

| REV | MADE | CHKD | APP | DATE | REVISIONS |
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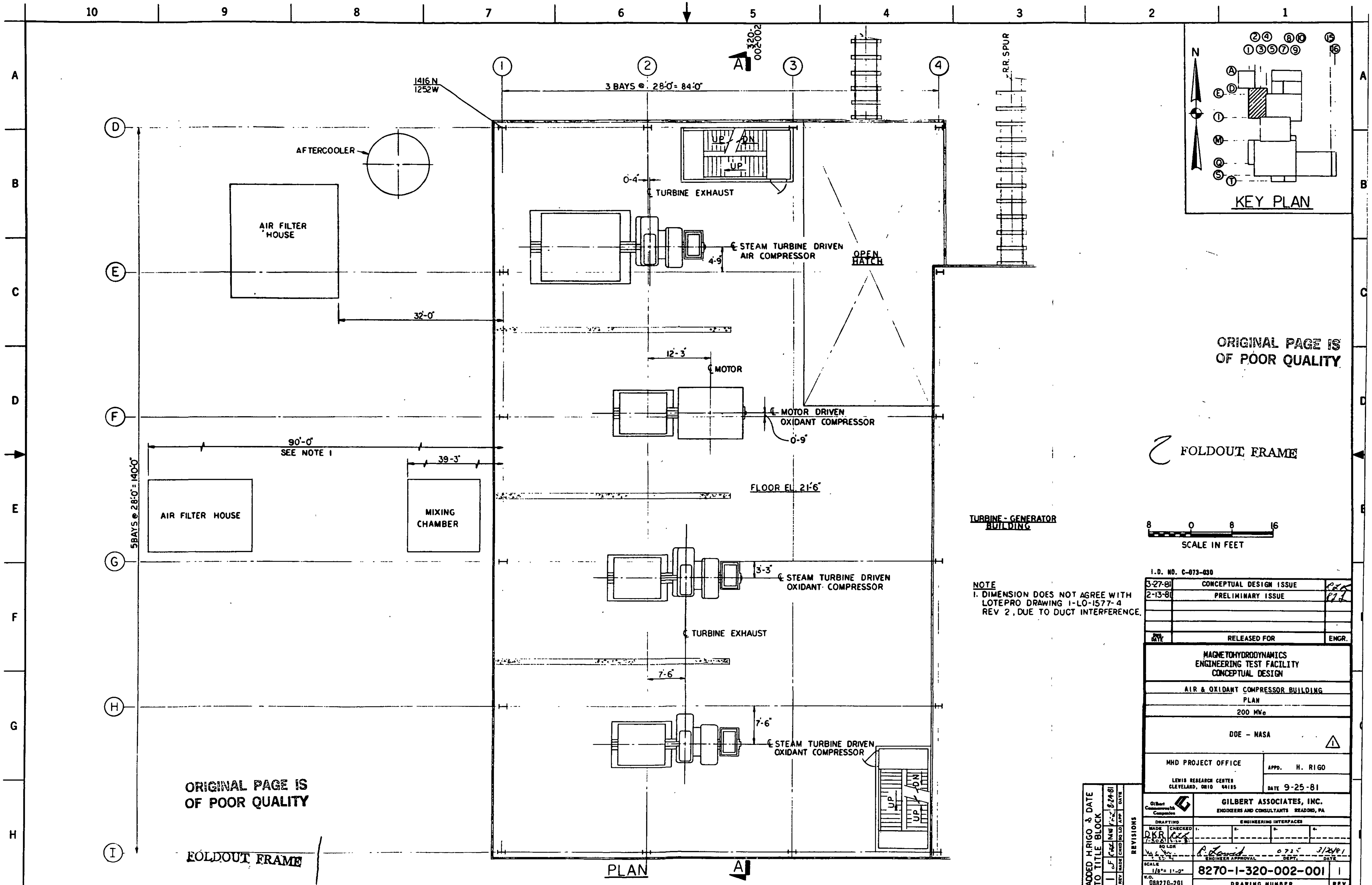

KEY PLAN
ORIGINAL PAGE IS OF POOR QUALITY
FOLDOUT FRAME
AFTERCOOLER
AIR FILTER HOUSE
AIR FILTER HOUSE
MIXING CHAMBER
1416 N
1252W
3 BAYS @ 28'-0" = 84'-0"
5BAYS @ 28'-0" = 140'-0"
R.R. SPUR
320-002-002
0'-4"
℄ TURBINE EXHAUST
℄ STEAM TURBINE DRIVEN AIR COMPRESSOR
4'-9"
OPEN HATCH
32'-0"
12'-3"
℄ MOTOR
℄ MOTOR DRIVEN OXIDANT COMPRESSOR
0'-9"
90'-0"
SEE NOTE 1
39'-3"
FLOOR EL 21'-6"
TURBINE - GENERATOR BUILDING
3'-3"
℄ STEAM TURBINE DRIVEN OXIDANT COMPRESSOR
℄ TURBINE EXHAUST
7'-6"
7'-6"
℄ STEAM TURBINE DRIVEN OXIDANT COMPRESSOR
UP
DN
PLAN
SCALE IN FEET
NOTE
1. DIMENSION DOES NOT AGREE WITH LOTEPRO DRAWING 1-LO-1577-4 REV 2, DUE TO DUCT INTERFERENCE.
I.D. NO. C-073-030
3-27-81 CONCEPTUAL DESIGN ISSUE
2-13-81 PRELIMINARY ISSUE
RELEASED FOR
ENGR.
MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN
AIR & OXIDANT COMPRESSOR BUILDING
PLAN
200 MWe
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LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135
APPD. H. RIGO
DATE 9-25-81
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SCALE 1/8" = 1'-0"
W.O. 088270-201
8270-1-320-002-001
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REV 1
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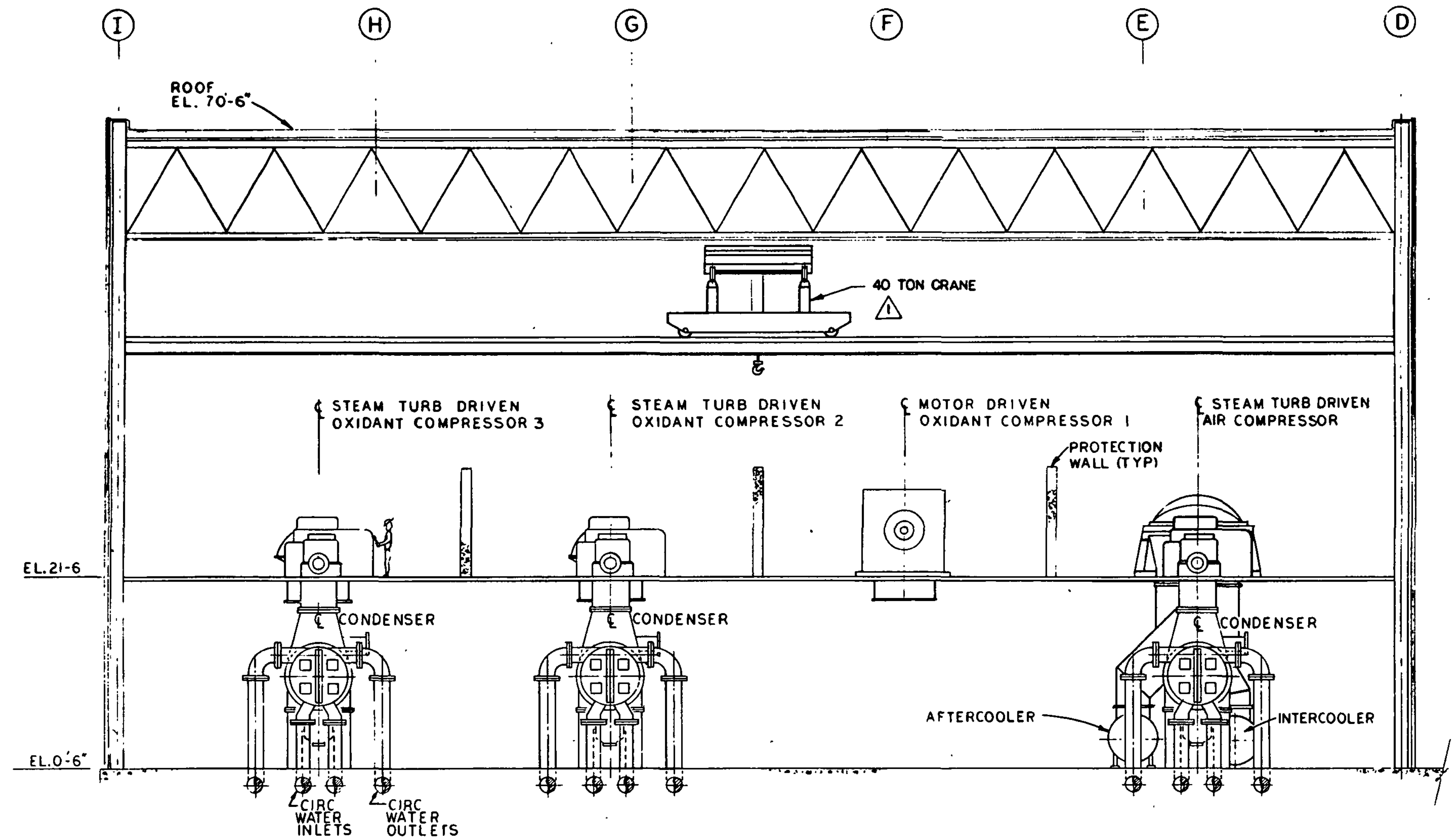


SECTION A-A

PLAN - DWG. 320-002-001



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I.D. NO. C-073-031

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| 3-27-81 | CONCEPTUAL DESIGN ISSUE | |
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MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

AIR & OXIDANT COMPRESSOR BUILDING

SECTION

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DATE 9-25-81

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| 1 | | | NW | | 8-24-81 | REVISED CRANE ORIENTATION ADDED H.RIGO & DATE TO TITLE BLOCK |

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ENGINEER APPROVAL — DEPT. 0725 — DATE 3/26/81

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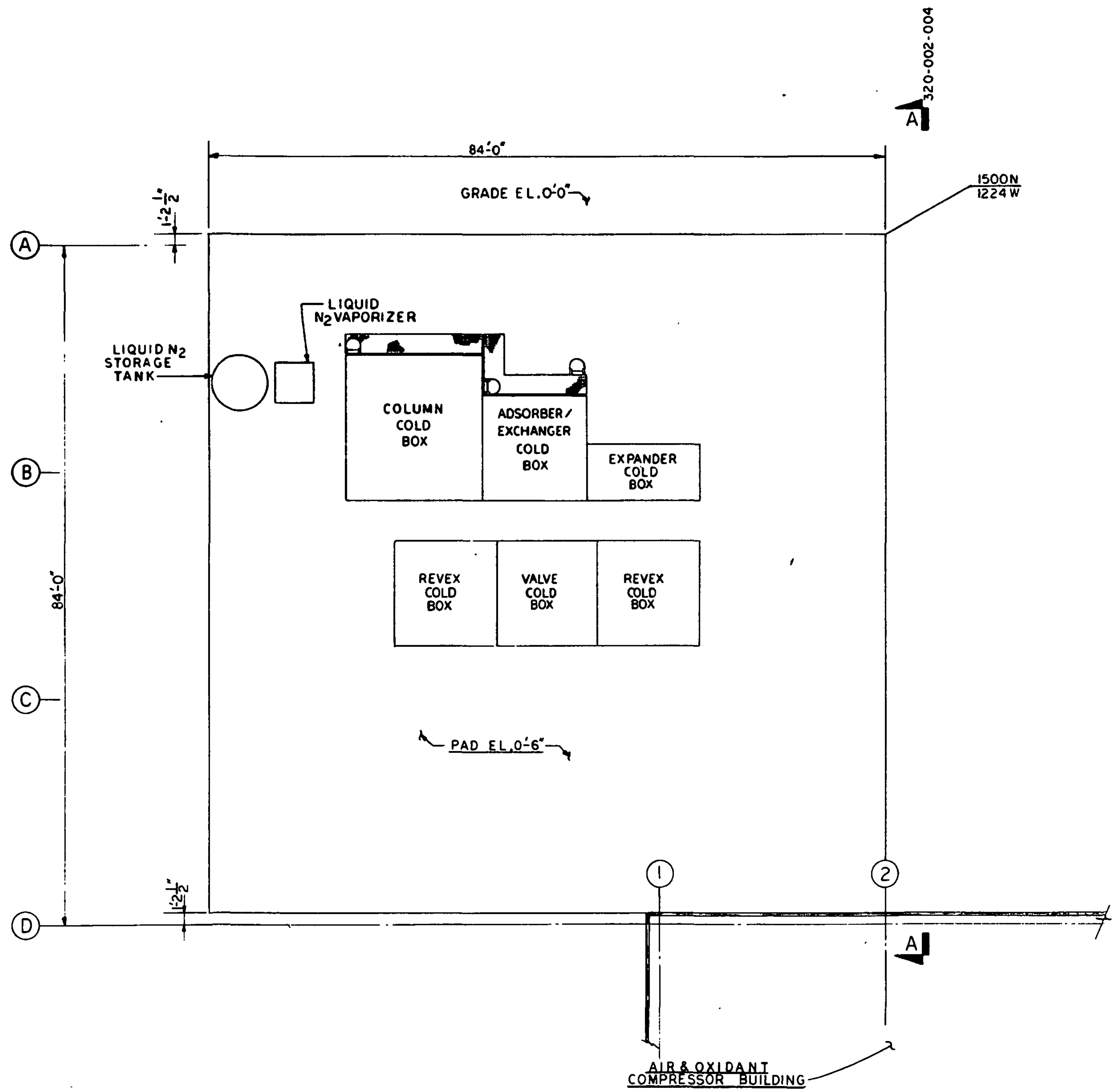
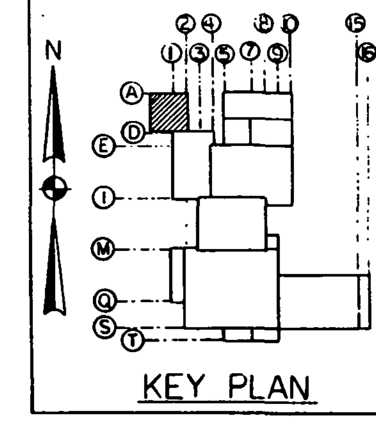



PLAN

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| 3-27-81 | CONCEPTUAL DESIGN ISSUE | |
| 2-13-80 | PRELIMINARY ISSUE | |
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MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

AIR SEPARATION UNIT

PLAN

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DATE 9-25-81

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| 1 | | | MW | | 8-24-81 | ADDED H.RIGO & DATE TO TITLE BLOCK |

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DRAFTING: MADE DKR 1-26-81; CHECKED; SQ LDR

ENGINEERING INTERFACES: 1. 2. 3. 4.

ENGINEER APPROVAL — DEPT. 6725 — DATE 3/26/81

SCALE 1/8" = 1'-0"

W.O. 088270-201

DRAWING NUMBER 8270-1-320-002-003 REV 1

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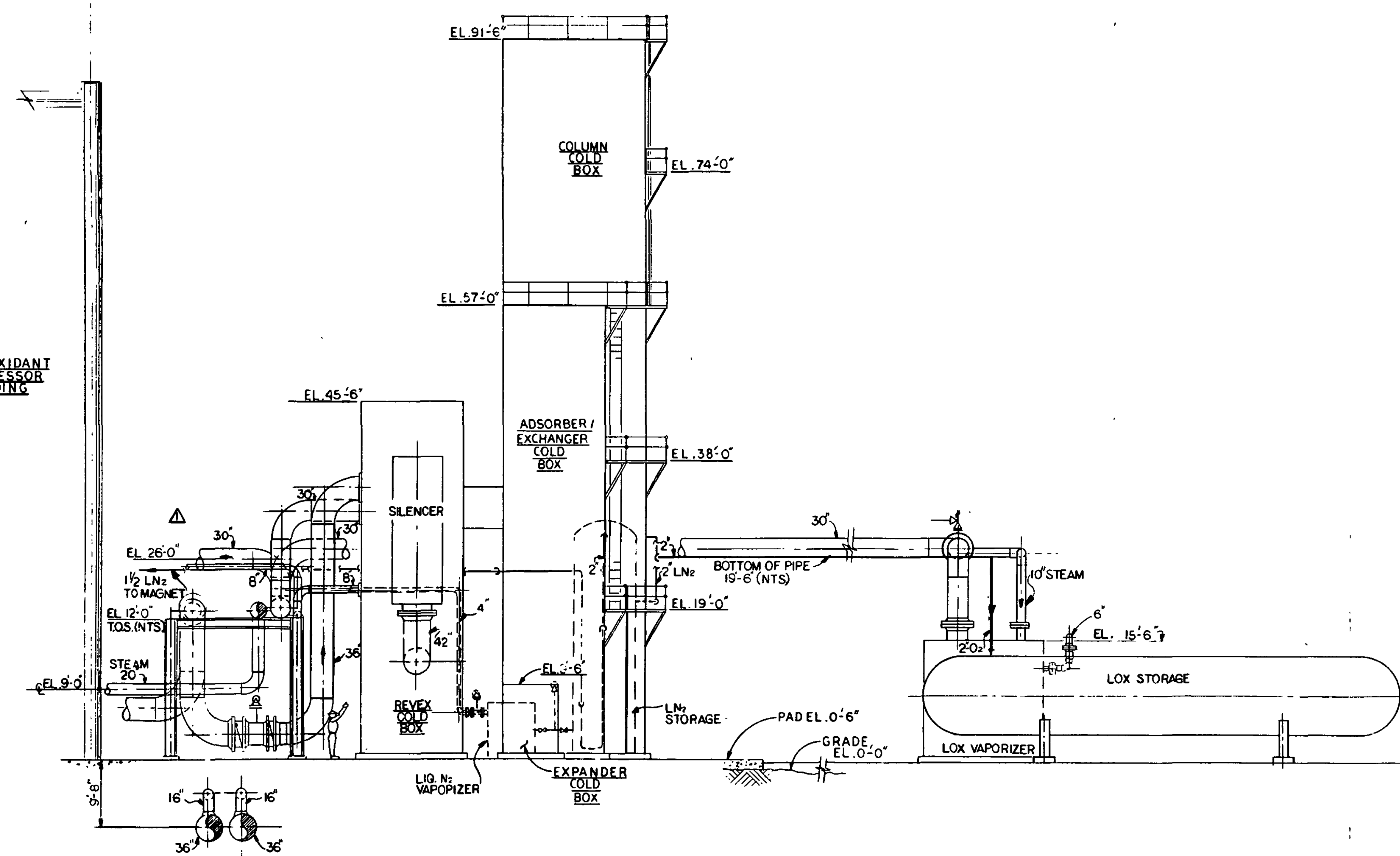


SECTION A-A
PLAN - DWG. 320-002-003

8 0 8 16
SCALE IN FEET

I.D. NO. 073-033

| DWG. DATE | RELEASED FOR | ENGR. |
|---|---|---|
| 3-27-81 | CONCEPTUAL DESIGN ISSUE | PTL |
| 2-13-81 | PRELIMINARY ISSUE | PTL |

MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

AIR SEPARATION UNIT
SECTION
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CLEVELAND, OHIO 44135

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DATE 9-25-81

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|---|---|---|---|---|---|---|
| 1 | CJJ | PTL | MW | CKL | 8-24-81 | REV PER LOTEPRO DWG. 1-LO-1577-7-2 ADDED H RIGO & DATE TO TITLE BLOCK |

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SQ LDR
ENGINEERING INTERFACES: 1. 2. 3. 4.
ENGINEER APPROVAL — DEPT. 0735 — DATE 3/26/81
SCALE 1/8" = 1'-0"
W.O. 088270-201
DRAWING NUMBER 8270-1-320-002-004 REV 1

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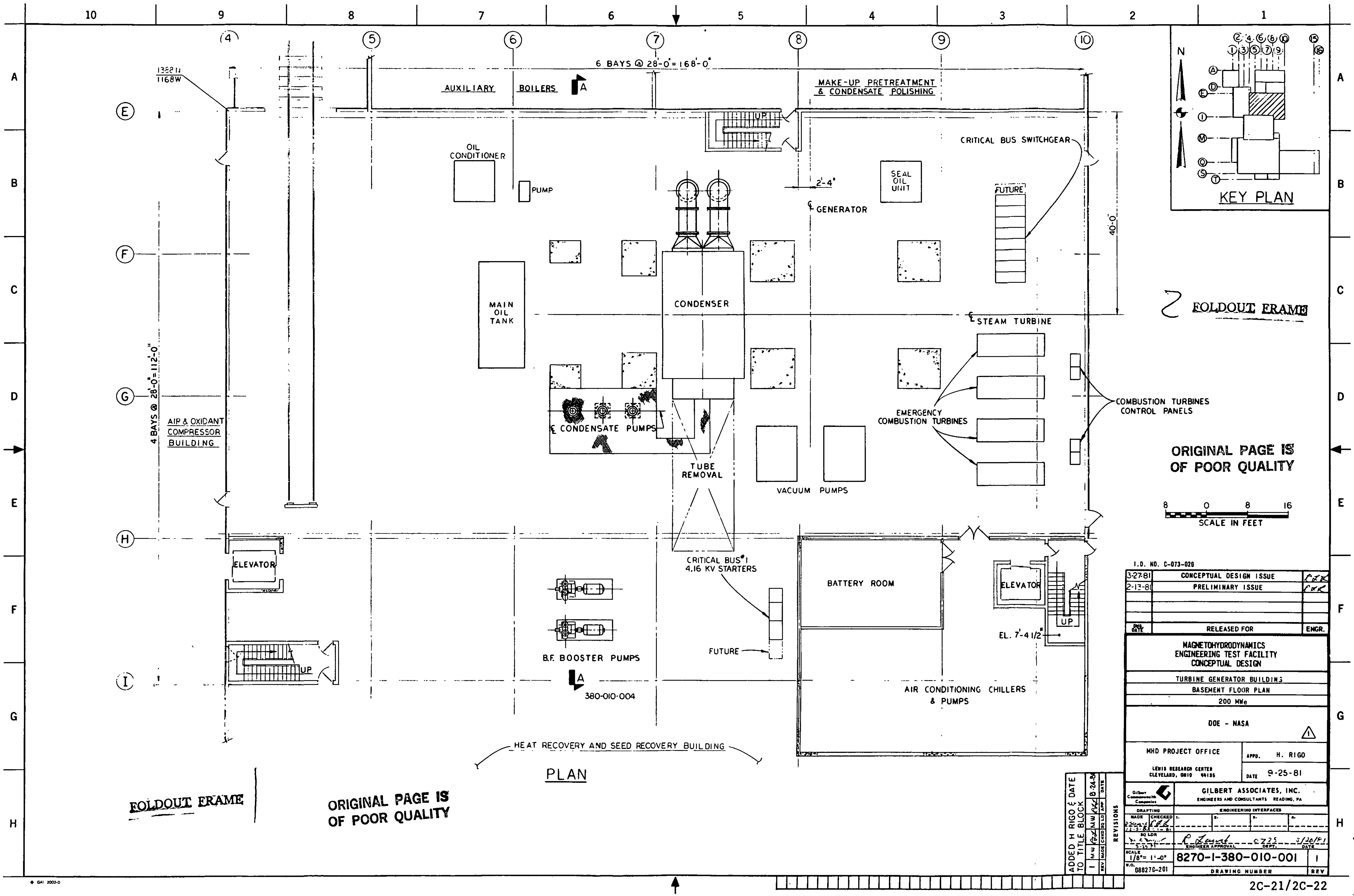

6 BAYS @ 28'-0" = 168'-0"
AUXILIARY BOILERS
MAKE-UP PRETREATMENT & CONDENSATE POLISHING
OIL CONDITIONER
PUMP
CRITICAL BUS SWITCHGEAR
SEAL OIL UNIT
FUTURE
2'-4"
GENERATOR
40'-0"
MAIN OIL TANK
CONDENSER
STEAM TURBINE
4 BAYS @ 28'-0" = 112'-0"
AIR & OXIDANT COMPRESSOR BUILDING
CONDENSATE PUMPS
EMERGENCY COMBUSTION TURBINES
COMBUSTION TURBINES CONTROL PANELS
TUBE REMOVAL
VACUUM PUMPS
ELEVATOR
CRITICAL BUS #1 4.16 KV STARTERS
BATTERY ROOM
UP
EL. 7'-4 1/2"
B.F. BOOSTER PUMPS
FUTURE
380-010-004
AIR CONDITIONING CHILLERS & PUMPS
HEAT RECOVERY AND SEED RECOVERY BUILDING
PLAN
KEY PLAN
N
FOLDOUT FRAME
ORIGINAL PAGE IS OF POOR QUALITY
SCALE IN FEET
8 0 8 16
I.D. NO. C-073-026
3-27-81 CONCEPTUAL DESIGN ISSUE
2-13-81 PRELIMINARY ISSUE
RELEASED FOR
MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN
TURBINE GENERATOR BUILDING
BASEMENT FLOOR PLAN
200 MWe
DOE - NASA
MHD PROJECT OFFICE
LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135
APPD. H. RIGO
DATE 9-25-81
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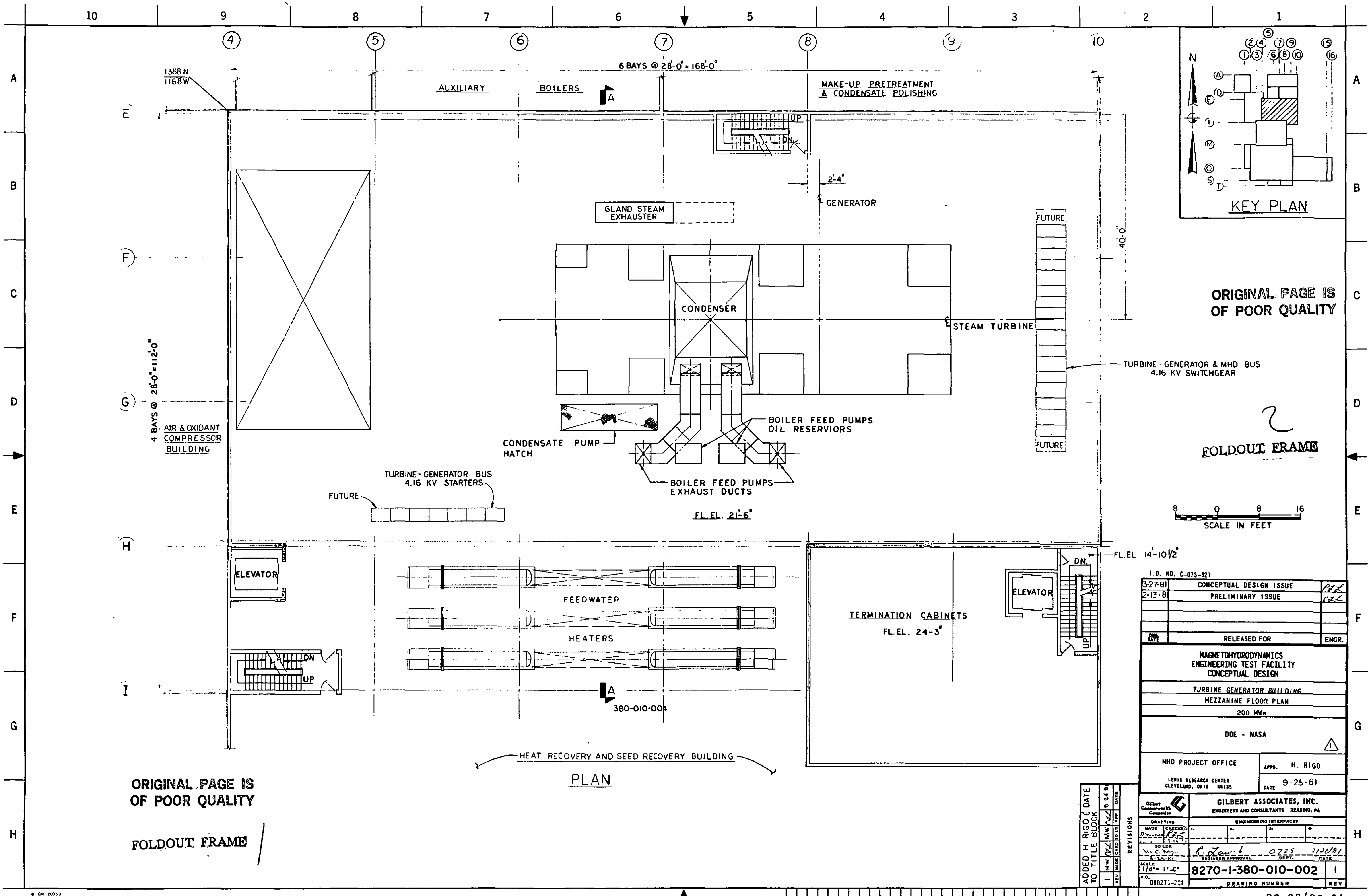
6 BAYS @ 28'-0" = 168'-0"
1388 N
1168 W
AUXILIARY BOILERS
MAKE-UP PRETREATMENT & CONDENSATE POLISHING
UP
DN
2'-4"
GENERATOR
GLAND STEAM EXHAUSTER
FUTURE
40'-0"
CONDENSER
STEAM TURBINE
TURBINE - GENERATOR & MHD BUS 4.16 KV SWITCHGEAR
4 BAYS @ 28'-0" = 112'-0"
AIR & OXIDANT COMPRESSOR BUILDING
CONDENSATE PUMP HATCH
BOILER FEED PUMPS OIL RESERVOIRS
BOILER FEED PUMPS EXHAUST DUCTS
TURBINE - GENERATOR BUS 4.16 KV STARTERS
FUTURE
FL. EL. 21'-6"
FL. EL 14'-10½"
ELEVATOR
FEEDWATER
HEATERS
TERMINATION CABINETS
FL. EL. 24'-3"
ELEVATOR
DN.
UP
380-010-004
HEAT RECOVERY AND SEED RECOVERY BUILDING
PLAN
KEY PLAN
SCALE IN FEET
8 0 8 16
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3-27-81 CONCEPTUAL DESIGN ISSUE
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MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN
TURBINE GENERATOR BUILDING
MEZZANINE FLOOR PLAN
200 MWe
DOE - NASA
MHD PROJECT OFFICE
LEWIS RESEARCH CENTER CLEVELAND, OHIO 44135
APPD. H. RIGO
DATE 9-25-81
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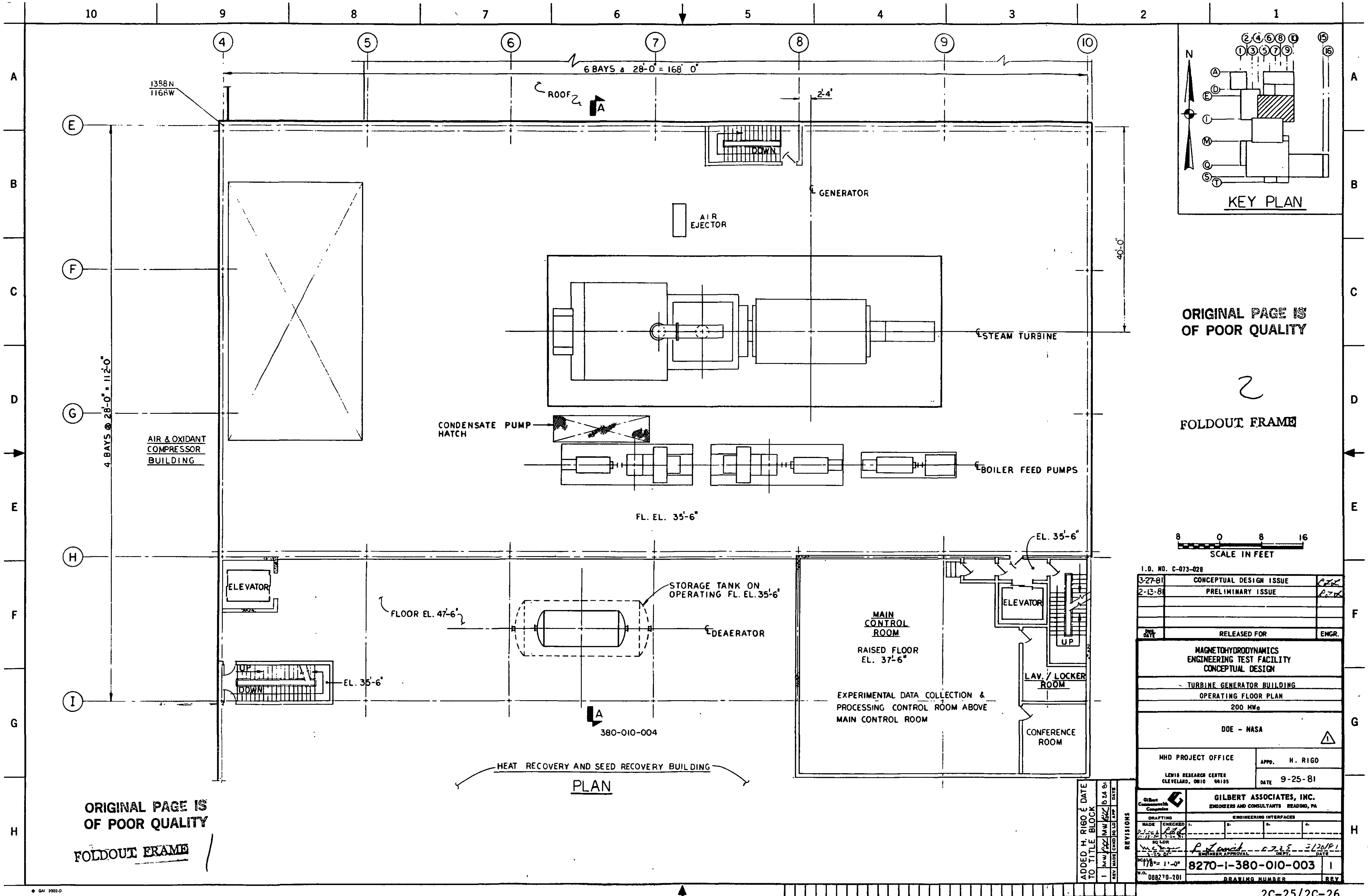
6 BAYS @ 28'-0" = 168' 0"
4 BAYS @ 28'-0" = 112'-0"
1358N
1168W
ROOF
2'-4'
DOWN
GENERATOR
AIR EJECTOR
40'-0"
STEAM TURBINE
CONDENSATE PUMP HATCH
AIR & OXIDANT COMPRESSOR BUILDING
BOILER FEED PUMPS
FL. EL. 35'-6"
EL. 35'-6"
ELEVATOR
STORAGE TANK ON OPERATING FL. EL. 35'-6"
FLOOR EL. 47'-6"
DEAERATOR
MAIN CONTROL ROOM
RAISED FLOOR EL. 37'-6"
EXPERIMENTAL DATA COLLECTION & PROCESSING CONTROL ROOM ABOVE MAIN CONTROL ROOM
LAV. / LOCKER ROOM
CONFERENCE ROOM
UP
DOWN
EL. 35'-6"
380-010-004
HEAT RECOVERY AND SEED RECOVERY BUILDING
PLAN
KEY PLAN
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TURBINE GENERATOR BUILDING
OPERATING FLOOR PLAN
200 MWe
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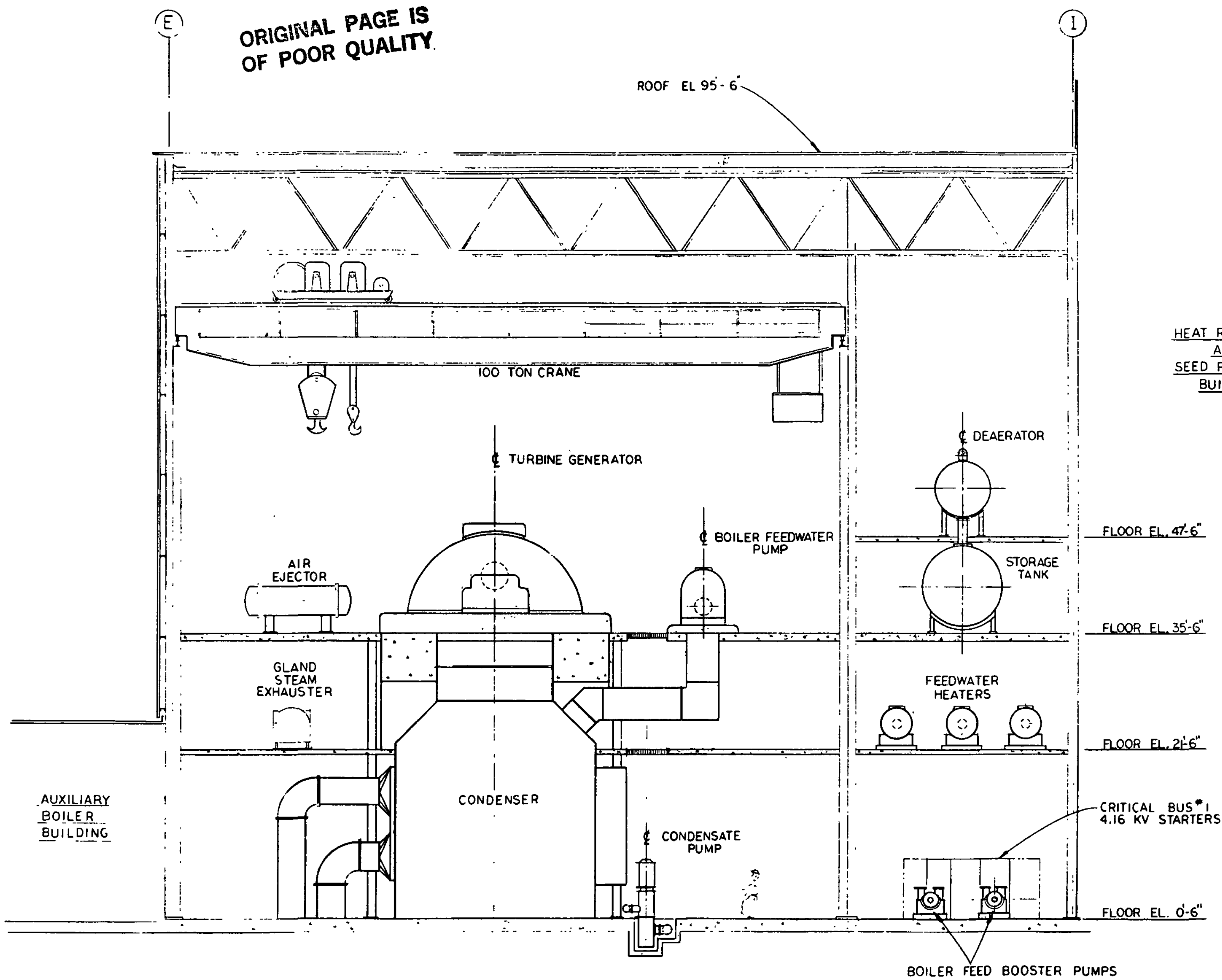


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SCALE IN FEET

## SECTION - "A A"

PLAN — DWG. 380-010-001
PLAN — DWG. 380-010-002
PLAN — DWG 380-010-003

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CONCEPTUAL DESIGN

TURBINE GENERATOR BUILDING
SECTION
200 MWe

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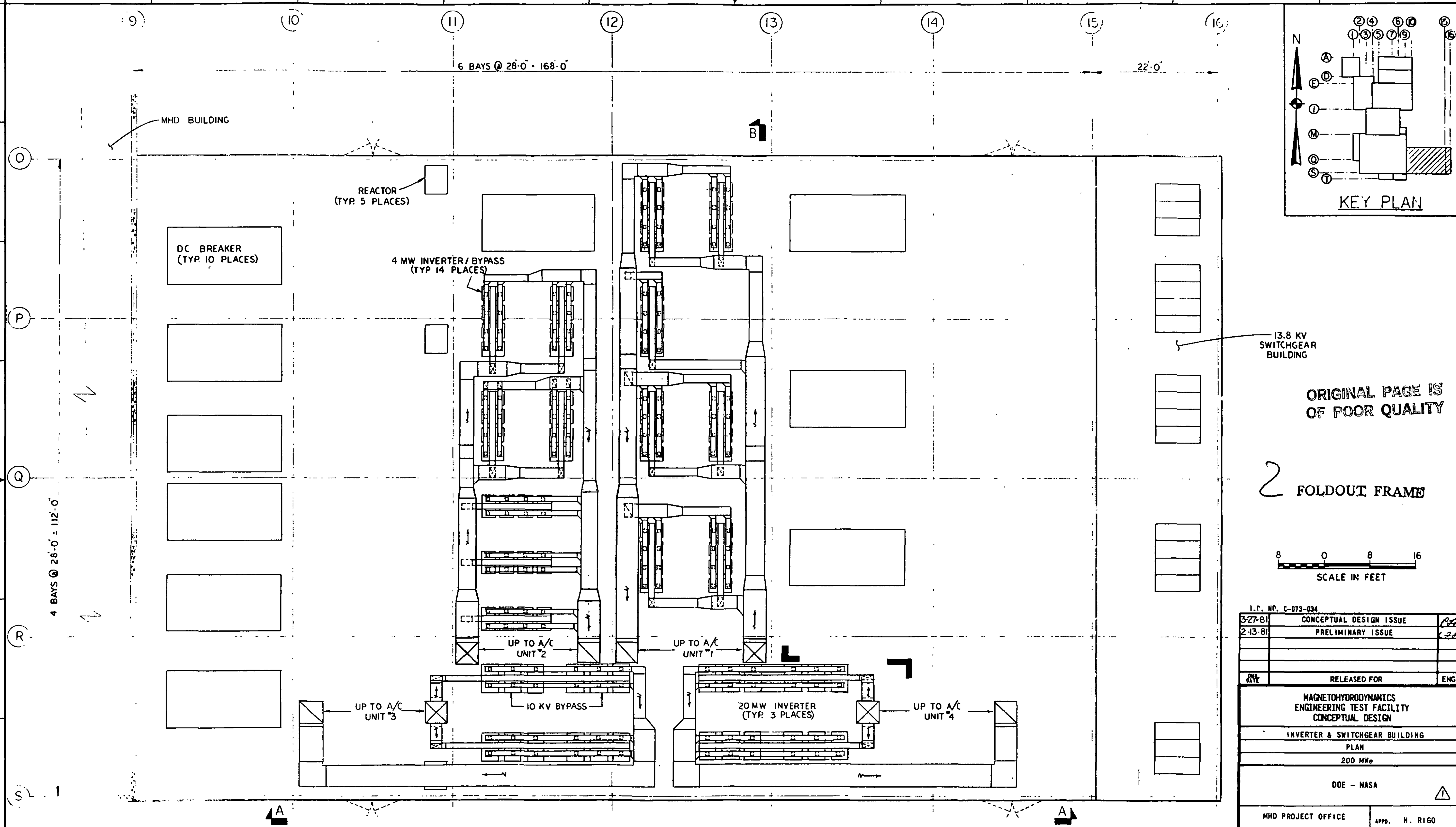


PLAN-FLOOR EL. 0'-6"

2 FOLDOUT FRAME

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ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

INVERTER & SWITCHGEAR BUILDING
PLAN
200 MWe

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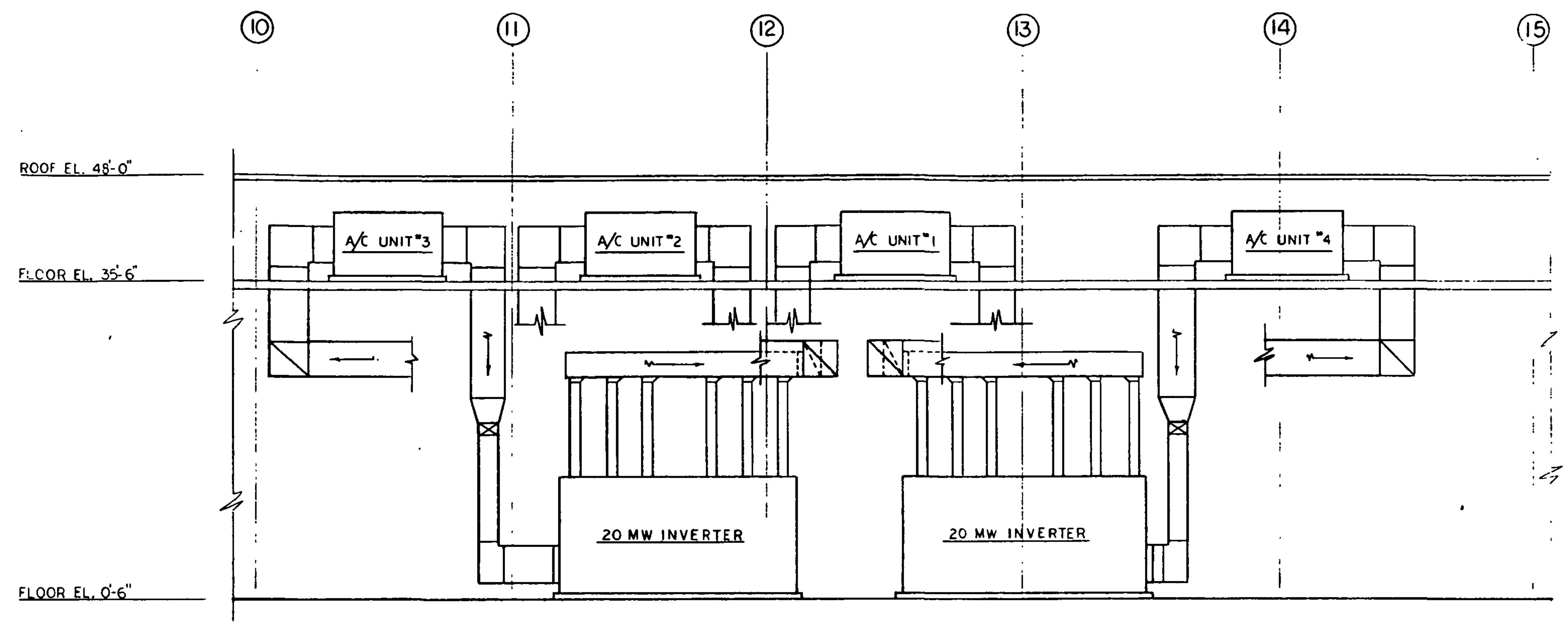


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SECTION - "A A"

PLAN DWG. 810-002-001

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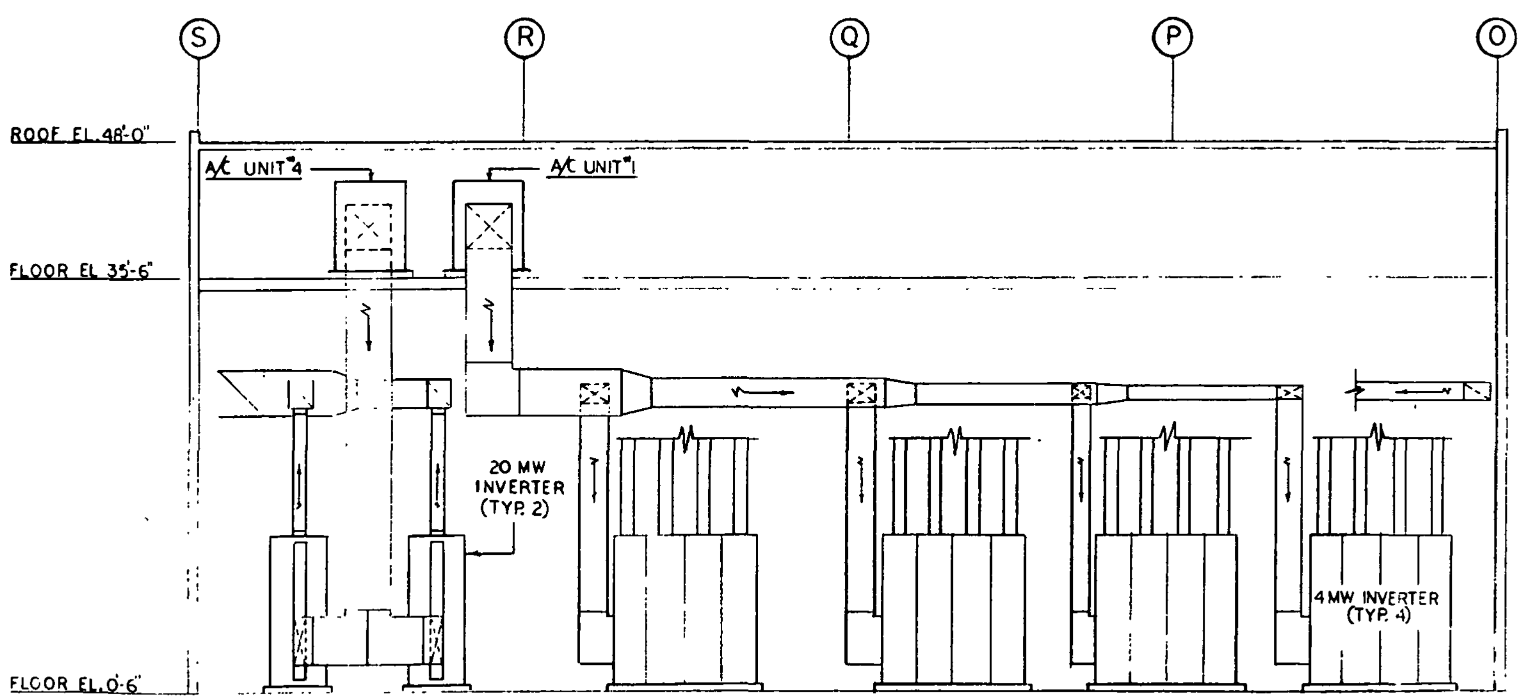


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PLAN DWG 810 002 001

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MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

INVERTER BUILDING

SECTION

200 MWe

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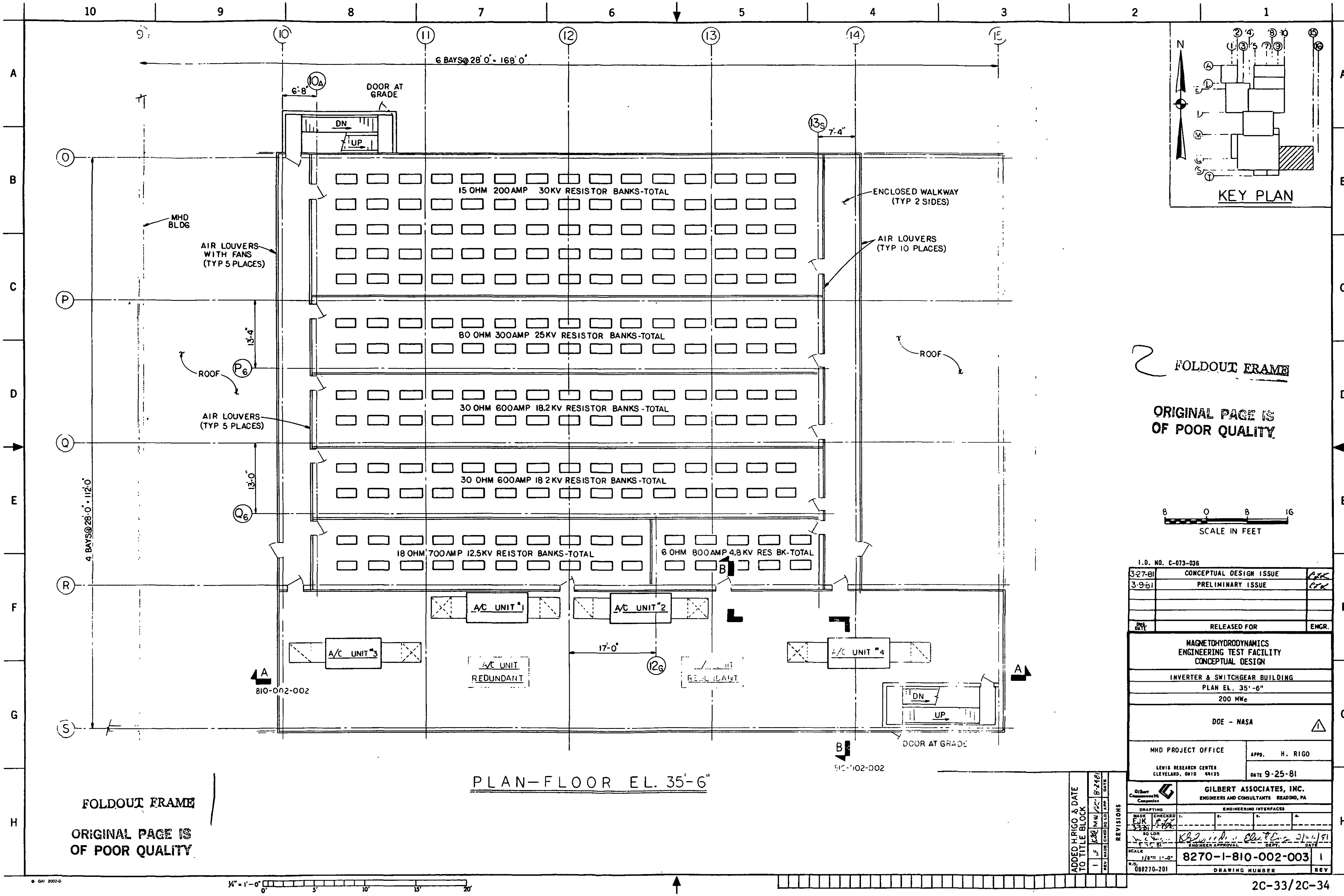

KEY PLAN
N
6 BAYS@28'0" = 168'0"
4 BAYS@28'0" = 112'0"
DOOR AT GRADE
DN
UP
MHD BLDG
15 OHM 200AMP 30KV RESISTOR BANKS-TOTAL
80 OHM 300AMP 25KV RESISTOR BANKS-TOTAL
30 OHM 600AMP 18.2KV RESISTOR BANKS-TOTAL
30 OHM 600AMP 18.2KV RESISTOR BANKS-TOTAL
18 OHM 700AMP 12.5KV REISTOR BANKS-TOTAL
6 OHM 800AMP 4.8KV RES BK-TOTAL
ENCLOSED WALKWAY (TYP 2 SIDES)
AIR LOUVERS (TYP 10 PLACES)
AIR LOUVERS WITH FANS (TYP 5 PLACES)
AIR LOUVERS (TYP 5 PLACES)
ROOF
A/C UNIT #1
A/C UNIT #2
A/C UNIT #3
A/C UNIT #4
A/C UNIT REDUNDANT
17'-0"
6'-8"
7'-4"
13'-4"
13'-0"
810-002-002
SCALE IN FEET
PLAN-FLOOR EL. 35'-6"
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INVERTER & SWITCHGEAR BUILDING
PLAN EL. 35'-6"
200 MWe
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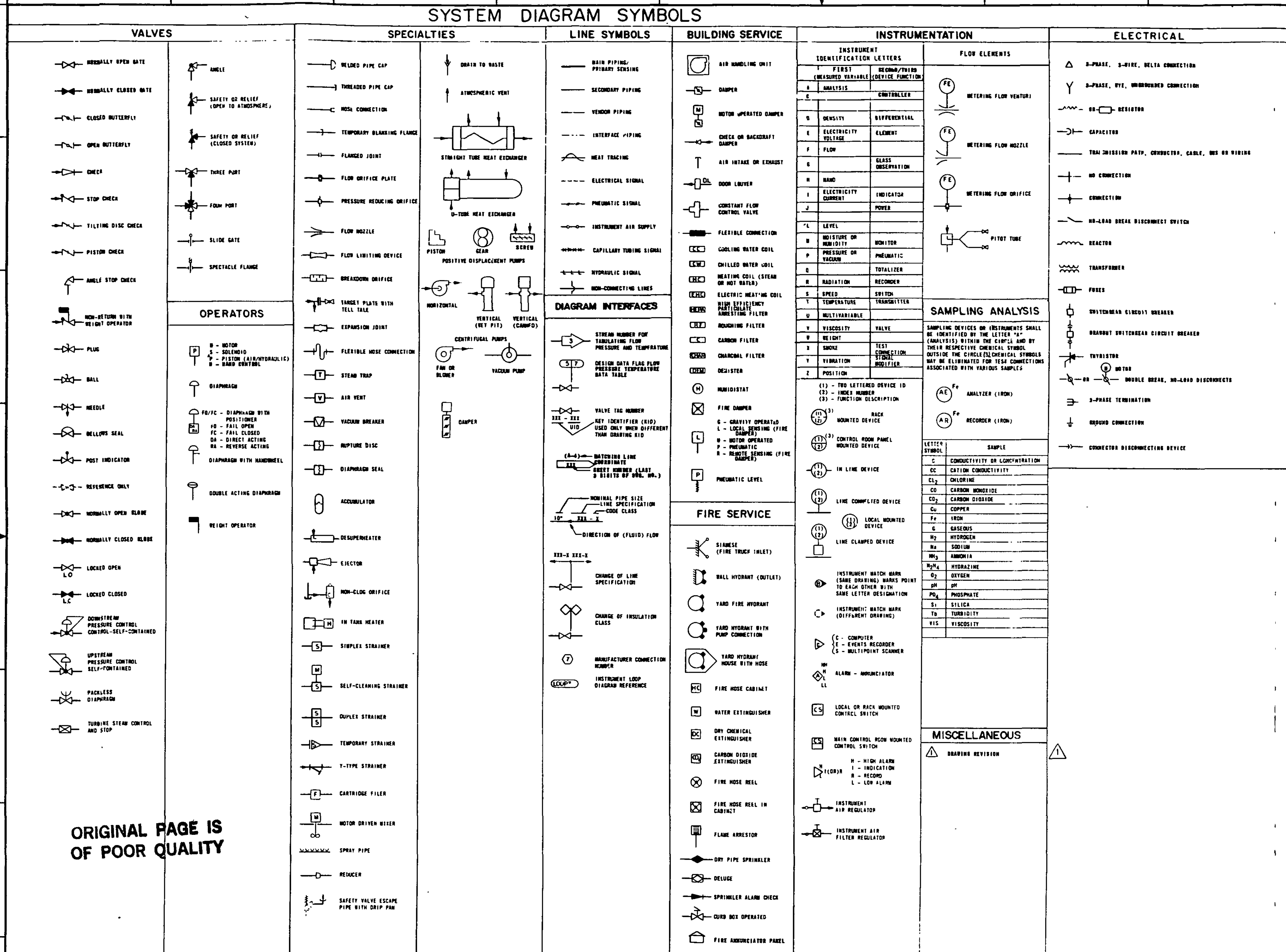
# SYSTEM DIAGRAM SYMBOLS

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MAGNETOHYDRODYNAMICS
ENGINEERING TEST FACILITY
CONCEPTUAL DESIGN

SYSTEM DIAGRAMS
SYMBOLS
200 MWe

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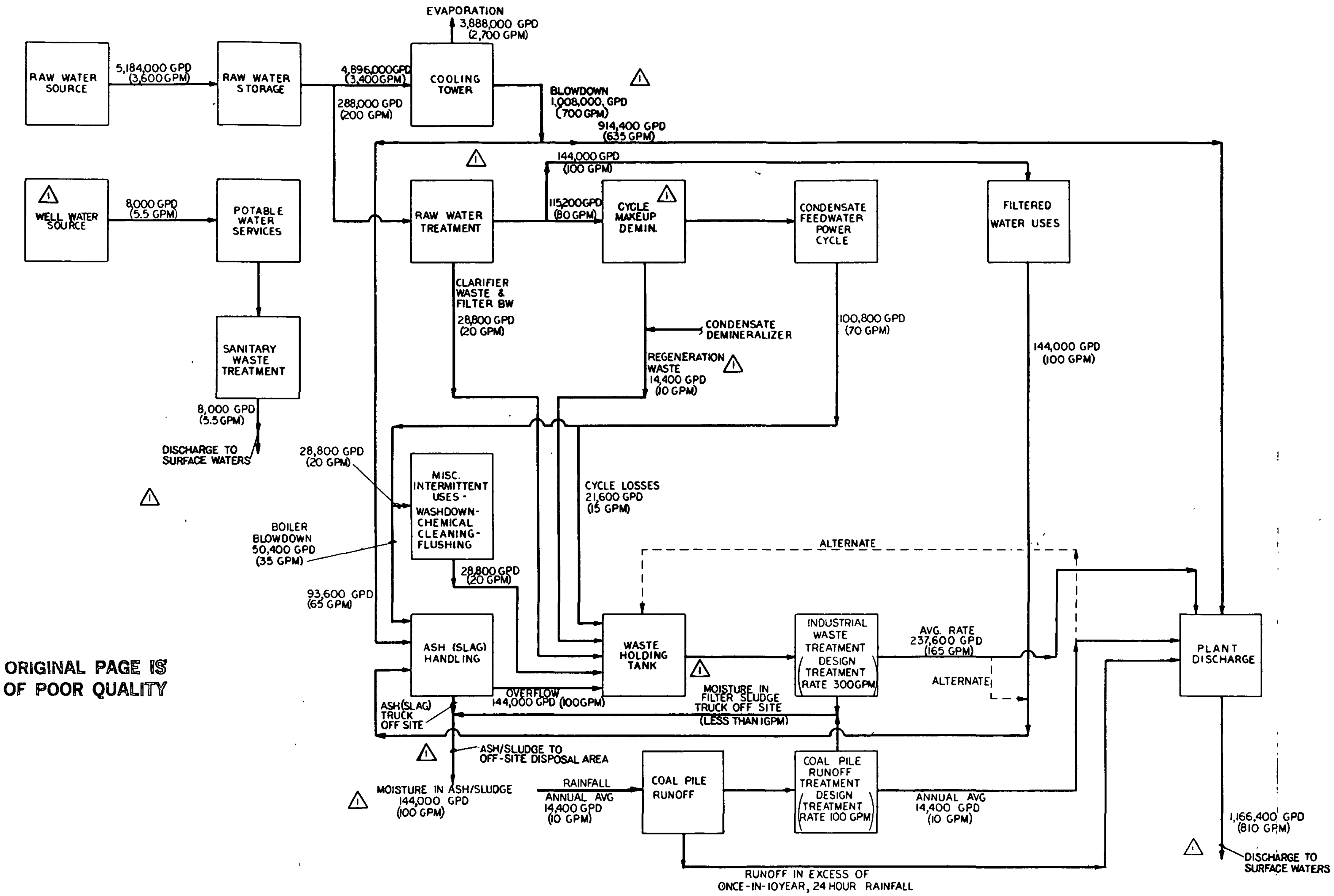
NOTES:

1. ALL FLOW RATES SHOWN ARE DESIGN FLOW RATES, EXCEPT AS NOTED.
2. SANITARY WASTE FLOW BASED ON POPULATION OF 200 AT MAIN MHD PLANT, 20 AT COAL HANDLING FACILITIES AND 35 GALLONS PER CAPITA PER DAY.



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MAGNETOHYDRODYNAMICS ENGINEERING TEST FACILITY CONCEPTUAL DESIGN

FLUID SYSTEM DIAGRAM
WATER BALANCE
200 MWe

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| 7. Author(s) Gilbert/Commonwealth | | 8. Performing Organization Report No. |
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| | | 14. Sponsoring Agency Report No. DOE/NASA/0224-1 |

15. Supplementary Notes

Final Report. Prepared under Interagency Agreement DE-AI01-77ET10769. Project Manager, Henri S. Rigo, MHD-ETF Systems Office, NASA Lewis Research Center, Cleveland, Ohio 44135.

16. Abstract

This report summarizes the reference conceptual design of the MHD Engineering Test Facility (ETF), a prototype 200 MWe coal-fired electric generating plant designed to demonstrate the commercial feasibility of open cycle MHD. Main elements of the design are identified and explained, and the rationale behind them is reviewed. Major systems and plant facilities are listed and discussed. The report also presents construction cost and schedule estimates, and identifies the engineering issues that should be reexamined. This report integrates the latest (1980-1981) information from the MHD technology program with the elements of a conventional steam power electric generating plant. It is presented in five volumes:

- Vol. I - Executive Summary
- Vol. II - Engineering
- Vol. III - Costs & Schedule
- Vol. IV and Vol. V - Supplementary Engineering Data (Issues, Background, Performance Assurance Plan, Design Details, System Design Descriptions and Related Drawings).

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|---|---|
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| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price* |
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